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DREDGES AND DREDGING ON THE MISSISSIPPI RIVER.

BY J. A. OCKERSON, M. Am. Soc. C. E.

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WITH DISCUSSION.

The Mississippi River is utilized for purposes of navigation from the Gulf of Mexico to the Falls of St. Anthony, a distance of about 2 000 miles.

In this great length, the character of the stream goes through various changes, through the influx of tributaries and other causes. In order to get a clear comprehension of the controlling physical conditions in different parts of the stream, it is best to divide it into four distinct reaches or sections.

First.—That portion extending from the Falls of St. Anthony to the mouth of the Missouri, a distance of 712 miles. In this reach the banks are low, and the oscillation between high and low water rarely exceeds 25 ft. In the upper half of this reach the river is divided into a great many sloughs, which serve as high-water channels, but are often nearly or quite dry at low water. The water carries but little sediment; bank erosion is comparatively slight; for 21 miles it flows through a lake of slack water 30 ft. deep; the flow in two places is in-

terrupted by rapids where the bed of the stream is solid rock; in the upper portion, the navigable depth at low water sometimes gets down to 2½ ft., and navigation is usually suspended during the winter season for a period of four months or more in consequence of the river being frozen. The low-water slope averages about 0.5 ft. per mile. The low-water discharge is about 25 000 cu. ft. per second, and the high-water discharge about 350 000 cu. ft. per second. High water generally comes in May and June, and the low-water season usually begins about the first of September and lasts until navigation is closed by ice.

One of the rapids spoken of, near Rock Island, Ill., 1 575 miles above the mouth, has been improved by the removal of rock and the concentration of the volume by dikes and dams. The other, above Keokuk, Ia., 1 445 miles above the mouth, is surmounted by means of a canal, with 8 miles of slack-water navigation and three locks, with a total lift of 18 ft.

Second.—The second reach extends from the mouth of the Missouri to the head of the alluvial basin of the lower river, or practically to the mouth of the Ohio, a distance of 210 miles. This reach is the first to take up the enormous load of sediment put upon it by the Missouri River. Here permeable dikes are at their best, and immense deposits are easily induced where channel contraction is desirable to increase the depth. The banks are somewhat higher than those of the first reach, and the effects of bank erosion are more noticeable. The extreme oscillation between high and low water near the upper portion of this reach is some 36 ft.; the low-water slope averages 0.6 ft. per mile; the low-water discharge is about 45 000 cu. ft. per second, and the high-water discharge about 850 000 cu. ft. per second. At low water the navigable depths on the bars often reach as low as 4 ft. Overflows are not very frequent, as a conjunction of the floods of the upper Mississippi and Missouri Rivers is necessary to produce an overflow stage. The high-water stages usually occur in May and June, and the low-water season begins early in September and continues into the winter months.

Sand bars are numerous, and the crossings are consequently frequent, and their locations are constantly shifting. The river washes the rocky bluffs on one side or the other a greater part of the distance, and at Gray's Point, 1 100 miles above the mouth, it flows through a rocky gorge for a distance of 7 miles. At the lower end the

normal conditions are often complicated by back-water from floods in the Ohio, which causes the sediment to deposit, and this is a prolific source of annoyance to navigation.

This reach is sometimes frozen over for a month or so during the winter, but is more often free from ice throughout the year. The whole reach partakes much of the character of the Missouri River.

Third.—This reach extends from the mouth of the Ohio to the mouth of the Red River, a distance of 750 miles. Here the Ohio, reinforced by the Tennessee and Cumberland Rivers, comes in and controls the flood conditions of the lower river. The Missouri River no longer dominates, except in its mud; the bed of the stream is now through the deposits which it has built up and torn down repeatedly; at a few points the river is held in check where it strikes the bluffs, but for the most part the banks yield readily to the eroding power of the current. At one place a straight reach becomes excessively wide, as near New Madrid, by the river encroaching first on one bank and then on the other; at another place it becomes exceedingly crooked, as near Greenville and above, by the continued erosion of the concave bank and the building out of the point opposite the bend. The caving reaches enormous proportions, the maximum lying in about the middle third of the reach; the oscillation between high and low stages reaches over 53 ft. The banks are high; overflows are frequent; the sand bars are very large in extent; islands and towheads are numerous, and the width of the river here reaches the maximum; the bars which obstruct low-water navigation are not very numerous, and the depth rarely gets below 5 ft. on these bars, while by far the greater part of the reach has water of ample depth to satisfy all demands of navigation; the river is rarely obstructed even by floating ice; low-water conditions which interfere with navigation rarely exceed four months in duration, and now and then entire years pass without any serious interruption to navigation; the low-water slope averages about 0.35 ft. per mile; the floods usually come in February or March, and the low-water conditions from September to December; many of the bends have depths of over 100 ft., and the discharge varies from 65 000 cu. ft. per second at extreme low water to 2 000 000 cu. ft. per second at extreme high water.

The work of maintaining navigable channels through the crests of the bars by means of dredging has, so far, been largely confined to this reach.

Fourth.—The fourth reach extends from the mouth of the Red River to the Gulf of Mexico, a distance of 310 miles. In this portion of the river the channel is narrow and deep, the banks tolerably stable, and sand bars as obstructions to navigation are almost unknown. So far as navigation is concerned, this reach requires neither contraction works nor dredging. Nature has built a channel which man vainly tries to imitate in the reaches lying above. Only two islands exist in this reach, and the last gravel bar is near the upper end of the reach. The upper limit at low water is only 3 ft. above mean Gulf level, and the tidal effect is often observed over the whole length of the reach. The first practicable outlet, for the waters coming down, is through the Atchafalaya at the head of this reach. The extreme oscillation between high and low water at the upper end of the reach is 50.4 ft., and this, of course, tapers down to zero at the Gulf. The river in this reach carries the burdens of all the tributaries coming from a drainage area of 1 250 000 square miles. The destructive floods invariably come from the Ohio Basin, augmented at times by the tributaries below the mouth of the Ohio River.

The characteristics of the reaches described are pronounced, and they differ so widely as to make the improvement of each a problem by itself. The last-named reach should perhaps have terminated at the Head of the Passes instead of at the Gulf, 12 miles farther down. Where the current of the river meets the slack water of the Gulf of Mexico, bars are formed which require special treatment.

A general view of the conditions has been presented in order to make it plain that the problem involves different treatment in different reaches of the river.

Sand Bars as Obstructions to Navigation.—It is not easy to find a satisfactory explanation as to why sediment piles up in ridges instead of being distributed evenly over the bottom. These ridges of sand are usually found on what steamboatmen call crossings; that is, on the path followed by boats when crossing from a pool lying in a bend along one bank to the pool in the bend of the opposite bank. These bars may be piled up to such an extent that during a high or even medium stage, their crests may be actually several feet higher than the surface of the water at low stage. The thread of the channel at high stages does not follow the low-stage channel, but crosses and recrosses it.

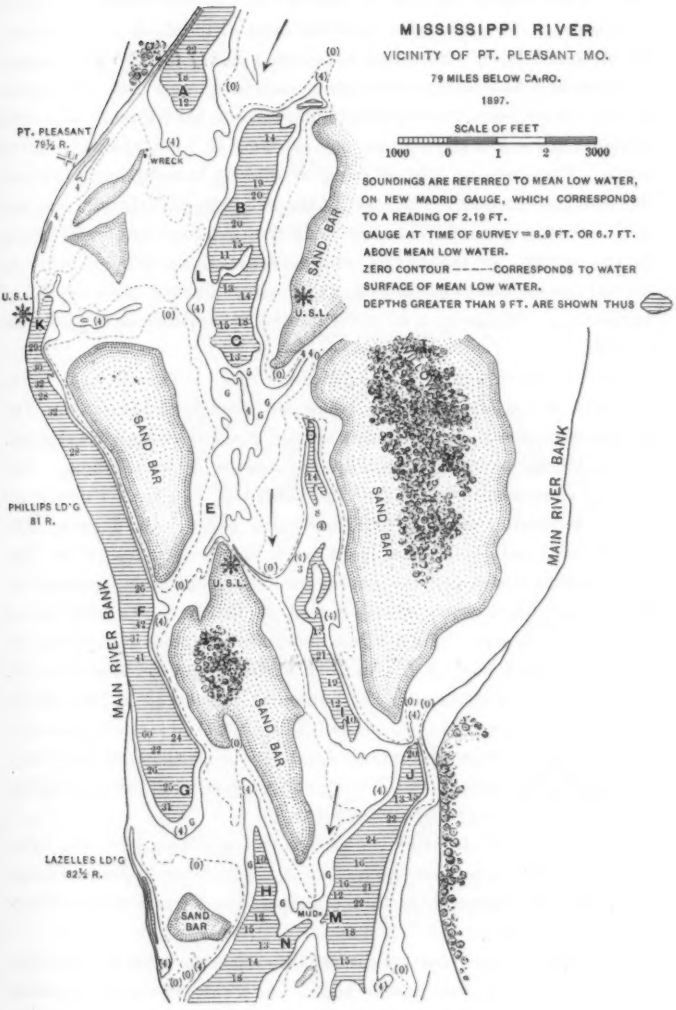

MISSISSIPPI RIVER
VICINITY OF PT. PLEASANT MO.
79 MILES BELOW CAIRO.
1897.
SCALE OF FEET
1000 0 1 2 3000
SOUNDINGS ARE REFERRED TO MEAN LOW WATER, ON NEW MADRID GAUGE, WHICH CORRESPONDS TO A READING OF 2.19 FT.
GAUGE AT TIME OF SURVEY = 8.9 FT. OR 6.7 FT. ABOVE MEAN LOW WATER.
ZERO CONTOUR ------ CORRESPONDS TO WATER SURFACE OF MEAN LOW WATER.
DEPTHS GREATER THAN 9 FT. ARE SHOWN THUS
PT. PLEASANT 79½ R.
WRECK
U. S. L.
SAND BAR
PHILLIPS LD'G 81 R.
MAIN RIVER BANK
LAZELLES LD'G 82½ R.
MUD
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

FIG. 1.

The first effect of a flood, with its increasing velocity, is to erode the bed and banks and add the material to the load already carried in suspension. This continues until the crest of the flood is reached and the decline sets in. The load is now too heavy for the diminishing velocity and the burden is rapidly deposited and obstructions are formed which, later, prove serious hindrances to navigation. When the river reaches a low stage these act as dams to hold the water in the pools. The slope on the crossing or dam is thereby increased, and likewise the velocity. The crest of the bar consequently cuts out, and if this cutting is confined to one channel a good navigable depth may be the result. If the bar is wide and flat there will probably be several insignificant channels, none of which answer the purposes of navigation. These must be concentrated by contraction or dredging, or both.

Fig. 1 shows rather a complicated case. This is near Point Pleasant, Mo., about 80 miles below the mouth of the Ohio. The general course of the river in this section is straight for several miles. The width is unusually great, due to erosion of both banks. The channel consequently is shallow and shifting. In Fig. 1 the pools are shown by parallel shading, and the figures indicate the depths. The upper pool comes down the right bank and terminates at *A*. The problem then is to reach the pool *B* over the reef which separates the two pools. When that point is reached, navigation to the lower end of the pool at *C* is easy. Then comes another crossing to *D*, followed by a narrow broken pool to *I*. Another crossing, and the fourth pool is reached at *J*. Here there is an abundance of water to *M*, then jumping a short reef into the deep pool at *N*, and this bad stretch of navigation is passed. Another route of more or less merit might have been found from the pool *B*-*C* at *L* to the shore pool at *K*, then following this long pool to *G* and over the reef to *H*.

Fig. 2 shows a simpler case and one most frequently met. The problem is simply to cross one reef lying between the upper and lower pools. Having crossed this, the depth is ample for several miles both above and below.

The problem then resolves itself into opening channels through the reefs between the successive pools. As a rule, the pools lie in the bends and the channel line crosses from one bank to the other. During the greater part of the year—say about nine months—the depth in

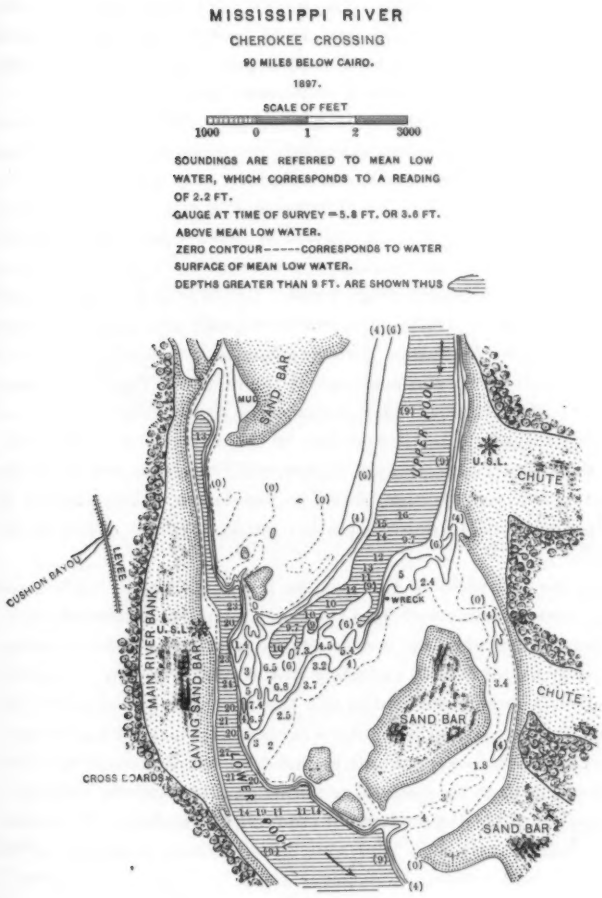

MISSISSIPPI RIVER
CHEROKEE CROSSING
90 MILES BELOW CAIRO.
1897.
SCALE OF FEET
1000 0 1 2 3000
SOUNDINGS ARE REFERRED TO MEAN LOW WATER, WHICH CORRESPONDS TO A READING OF 2.2 FT.
GAUGE AT TIME OF SURVEY = 5.8 FT. OR 3.6 FT. ABOVE MEAN LOW WATER.
ZERO CONTOUR------CORRESPONDS TO WATER SURFACE OF MEAN LOW WATER.
DEPTHS GREATER THAN 9 FT. ARE SHOWN THUS
SAND BAR
MUD
UPPER POOL
U.S.L.
CHUTE
CUSHION BAYOU
LEVEE
WRECK
MAIN RIVER BANK
CAVING SAND BAR
SAND BAR
CHUTE
CROSS BOARDS
LOWER POOL
SAND BAR

FIG. 2.

the river below the Ohio is ample for the requirements of navigation. During the other three months navigation is sometimes practically suspended in the third reach on account of shallow water. Whatever is done in the way of opening the reefs at such times answers for one low-water season only. The next flood probably changes the thread of flow to such an extent as to cross the opened channel and obliterate it completely. This is repeated with each high and low stage.

So far, the problem seems simple enough. The only thing necessary is to open a cut through the reef, composed principally of loose sand; but there are other difficulties familiar only to the engineer who has been taught by long observation and experience. While this artificial cutting is going on, Nature is doing some cutting on her own account, but on such a gigantic scale that the work of the largest centrifugal pumps seems insignificant. By the time the engineer gets what he considers a dredge of enormous capacity into position to open a cut from *A* to *B*, Nature perhaps changes her mind and opens a channel of her own down along the shore to *K* (Fig. 1); or, what would be worse, throws such a volume of deposit over the bar *A-B* that the dredged cut is filled as fast as the material can be removed. It is this tremendous volume of material that is moved along the bottom by the current, complicated by unforeseen, subtle changes in direction and force of flow, that often mocks the best efforts of the engineer.

That the difficulties of the problem are not generally understood or appreciated is manifest from the many simple solutions offered by inventors. Men who have never seen the river are prolific in devices for remedying all defects at trifling cost of time or money. They are by no means alone in the matter, for the men who have spent a lifetime on the river steamers also have ideas, sometimes very good ones, which they have developed and confided to the Patent Office. One inventor appeals to the Secretary of War for some "secret position," where he can study the currents of the river unobserved. He says he has a "nack of inventing," and also "has the nack of getting information." Furthermore, he believes there is some "sculluglery" going on which he might expose. He hesitates about giving his talents to the world, but says he is "willing to confide in the Government." He further says: "Necessity has been the mother of invention with me. Hydraulic engineers may oppose and discourage

my project and design, as it is calculated to do away with their work." With his device, "St. Louis would be a port for loading vessels direct from forring ports."

The necessity for some suitable device for the removal of sand bars has long been felt. Some thirty years ago a board of engineers recommended that a prize of $100 000 be offered for the best device for removing obstructing sand bars from navigable streams. Although Congress did not carry out their recommendation by making the necessary appropriation, a great many inventions have appeared

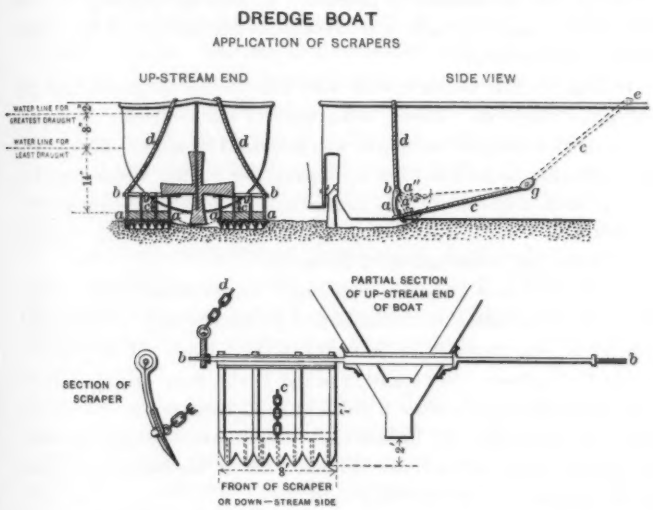


FIG. 3.

from time to time and have been tendered to the Government for use. A description of some of these may be of interest.

These devices can be divided into four general classes, viz., stirring and scraping, current deflectors, jets and the suction dredge.

STIRRING AND SCRAPING DEVICES.

(1) About the earliest application of this principle on the Mississippi was in 1867, when it was decided to improve Pass à Loutre by means of excavating and stirring or harrowing up the minute alluvial

material deposited from the heavily laden waters of the river. In this work a double-ended dredge boat, having an excavating screw with four blades 14 ft. in diameter, was used. This screw was similar to an ordinary propeller wheel and was similarly mounted. It was turned by means of a double engine at the rate of 60 revolutions per minute. It reached a depth 2 ft. below the keel. The work of the screw was made more effective by means of an auxiliary scraper attached to the up-stream end of the boat on either side of the keel (Fig. 3). The boat was moved down stream over the bar with the screw operating and the scrapers in position. In this way some of the bar material was again brought into suspension and carried off into deep water by the current.

During the first month's work with this dredge the depth was not materially improved. Later, better success was realized. In a little less than two months the depth was increased from 11 to 17 ft. The chief difficulty seemed to be in weak propeller blades, which were frequently broken and could only be renewed by docking the vessel.

This device was intended to cut out and maintain a 20-ft. channel through the bar at the mouth of the river.

(2) At Southwest Pass the same result was expected from the use of conical screws attached to the bow of a suitable boat. These cones were 20 ft. long and 5 ft. in diameter at their bases. They were set so that their points came together at the boat's stem and their bases were separated so as to cover a width of 20 ft. from out to out. Their axes were horizontal, the salient angle they formed being foremost. The flanges of the screws were 12 ins. wide at the base of the cones and diminished to 6 ins. at the points.

When these enormous screws were put in motion it was very difficult to guide the boat. The material was readily plowed up, but it was not broken sufficiently fine to be carried away by the current.

(3) In 1867 there was appropriated the sum of $96 000 for the construction and operation of two scrapers or dredges on the upper Mississippi, between St. Paul and the mouth of the Illinois River.

The first efforts made to remove sand bars by means of the scrapers invented by Col. Long was in the fall of 1867. These scrapers consisted of a frame attached to the bow of a boat and carrying a heavy cross-bar, to which were attached 6 steel buckets or cutters. This frame could be raised or lowered at will. In operating, the boat went to the

upper side of a reef, the scraper was lowered and the boat was then backed slowly down stream, scraping the sand with it down to deep water below the reef. This operation was repeated until the desired depth was obtained.

Two side-wheel steamers, the *Montana* and the *Caffrey*, were equipped with these scrapers by the Government, and, for a time, the steamboat owners operated a scraper boat between Keokuk and St. Louis at their own expense.

The *Montana* was 210 ft. long, 35 ft. beam and 5½ ft. depth of hold. She was equipped with two engines having 20-in. cylinders and 7-ft. stroke. The *Caffrey* was 150 ft. long, 30 ft. wide, 4½ ft. hold, with a draught of 32 ins. She had 15-in. cylinders with 5-ft. stroke.

This last boat was equipped and ready for work in October, 1867. Her first work was on a bar near Gray Cloud, 17 miles below St. Paul. Only 3½ ft. could be carried over this bar, and the regular packets could not cross it. After about four hours' work with the scraper the depth was increased to 3½ ft. entirely across the bar. The scraping was continued for two days and a depth of 4 ft. was secured. By November 15th all the bars between St. Paul and Prescott had been scraped and the depths increased to 3½ or 4 ft. At that date the packet companies notified the engineer in charge that the scraping had removed all obstructing bars and that no more work was required.

In 1868, when navigation became difficult, the scrapers were put into commission and worked throughout the season. They succeeded in deepening the bars from 8 to 18 ins., and this was generally accomplished with a few hours' work. Beef Slough was deepened from 3½ ft. to 4½ ft. in 35 minutes.

On the whole, the results were so satisfactory that steamboat owners announced that their boats had been making regular trips without interruption, "a condition of affairs never before known at this stage of river in the experience of pilots of 35 years' standing." The largest steamers had been able to reach St. Paul in the low-water season during two successive years, when without the aid of the scrapers they would have been obliged to tie up. Steamboat men said:

"These scrapers can be relied on to increase the depth over the crests of the bars at low water from 8 to 12 ins. This nearly doubles the carrying capacity of the boats now in use."

This scraping was continued for several years at a cost of about $20 000 per annum for each steamer, but as the relief was only temporary and had to be repeated from year to year, it finally gave place to the so-called permanent improvement, consisting mainly of channel contraction.

It should be borne in mind that in the portion of the river where the above-described scrapers were used, the obstructing sand reefs are quite short.

(4) An "excavator for water courses having current" consists of a horizontal shaft attached to the stern of a suitable boat, and fitted with a series of serrated metallic disks 40 ins. in diameter. Each disk has 29 cutters or teeth, which are turned alternately in opposite directions. These disks are revolved by the necessary machinery, at the rate of 100 revolutions per minute. The bar to be removed is cut out by running back and forth until the required depth is obtained. It is claimed that this device "is found highly efficient in raising deposits in channels and separating the earth into small particles so that it may be carried off by the current," and that the amount of work it can accomplish in a given time is "equal to that of 249 common bucket-dredging machines."

It is well to note that these claims are not based on actual trial in practical work.

(5) A "submarine plow," attached by means of timbers to the sides of a boat, aims to plow out a furrow in the bar. Spiral springs are attached to the timbers holding the plow so as to force it down to its work, and so that it will adapt itself to any irregularities of the bottom. The efficiency of the plow is increased by water-jets forced into the furrow for the purpose of breaking up and scattering the deposit moved by the plow. Beyond this, the current is relied on to carry the deposit to deep water.

(6) A "channeler," consisting of a horizontal revolving drum made of boiler iron, with a series of plows and scrapers attached to its convex surface, is conspicuous among the earlier inventions. The revolving drum is 40 ft. long, and is suspended by journals near its extremities. It is revolved by means of two 35-H.-P. engines, which operate the drum through gear wheels acting on a large cog wheel encircling the drum half way between the ends.

The scrapers are set spirally on the drum for the purpose of carry-

ing the material outwardly each way from the middle. When the material reaches the end of the drum it is supposed that the current will take it up and carry it away, leaving a clear cut equal to the length of the drum. The drum and its shaft are attached to the stern of a boat. In this case the attachment is rigid, and the depth is adjusted by means of water-tight compartments in the boat which can be filled and pumped out at will.

In operating this device the boat is dropped down on a bar with bow end upstream. The drum is then made to revolve as the boat moves down on the reef. By means of anchors and lines attached to windlasses, the boat is drawn stern foremost down across the bar as rapidly as the scrapers on the drum loosen up and remove the deposit. It was supposed that the excavated material would be thrown from the ends of the drum with sufficient force to carry it entirely free from the cut, and it was estimated that in sand this device could make a cut 40 ft. wide and 3 ft. deep at the rate of 150 ft. per hour.

In moving from one bar to another the drum is used to propel the boat, which in this way, it was claimed, could travel at the rate of 8 miles per hour. The estimated cost of a craft of this kind was $25 000. A crew of 12 men was required to operate it.

Like many others, the merits of this device were never tested by actual work on sand bars.

(7) Another "scraper" consists of two arms, each 80 ft. long, placed parallel to each other and hinged at their middle points on the stern overhang of a side-wheel steamer. At the outer extremities of these arms is fastened a cross-beam, to which is hinged the scraper backing, which is rectangular in shape and made of boiler iron properly stiffened. Several scoop-shaped scrapers and plows, placed alternately, are attached to the lower edge of the backing. From each end of this cutter a chain leads to the steamer, for the purpose of taking up the strain and regulating the inclination of the scrapers. The scraper is raised or lowered by tackle leading from the inboard end of the arms to a drum on the deck of the steamer.

With this scraper the boat moves over the bar from its up-stream side and with head down stream. The sand is thus scraped down to the deep water. The operation is repeated until sufficient depth is obtained.

(8) "A steam circular sand bar dredger" was brought to public notice in 1878. This machine commended itself on "account of its practicability." With it, the inventor says:

"There is no need of costly engineering and surveys, no examinations to be made and no commissioners to report on what is necessary to be done. As a sand bar dredger it is invaluable; commencing at the lower edge of a sand bar by lowering the wheel to the required depth, a channel may be cut through in a remarkably short space of time, the current of the river carrying away the sand displaced by the revolving toothed wheel."

This machine was also intended for opening channels through ice. It was claimed that it could cut its way through solid ice 2 to 3 ft. thick at the rate of 4 to 6 miles an hour, and thus open a channel wide enough for steamboats.

"The harbors of the world heretofore closed by ice from 3 to 5 months in the year can be kept open so that ships can go to sea every day in the year." "One of these boats on each canal level would keep them open to commerce during the winter."

Offers were made to "guarantee" 10 ft. of water in the channel of the Mississippi River from St. Louis to Cairo in the driest season, with one "dredger" costing $40 000.

"The advantages of this invention to the commerce of the world is beyond computation."

(9) Another scraping device consists of a steel hull with a wedge-shaped prow, with auxiliary wings attached. This was intended to act something like a huge snow-plow, the wings or deflectors being designed to carry the loosened material far out each way from the cut. Jets were also provided to loosen up the material.

In actual operation the hull is sunk to the bottom by admitting water, and is then pulled up stream by powerful towboats. The wedge-shaped prow buries itself in the sand, which is pushed along as the boat is moved, and finally finds its way out to the ends of the deflectors. In moving from one bar to another, the boat is first floated by pumping the water out. This is a comparatively new device.

(10) Another comparatively recent device consists of a gigantic harrow having a water-jet at the extremity of each tooth. The pressure chamber forms the frame of the harrow. This harrow was to be attached to the bow of a boat and be provided with suitable rigging and winches by means of which it could be raised or lowered at will.

(11) A different design, or, as the inventor calls it, "Means for deepening the channels of rivers," consists of four "circular plows," or agitators, revolving on vertical shafts passing through the hull and operated by the necessary driving engines and gearing. Each screw can be raised or lowered independently, as required. These screws are intended to loosen up the material, and the natural current is supposed to do the rest. The forward pair of screws are smaller than the others, for the purpose of first opening a small channel, which is widened by the two which follow. The boat is moved back and forth until the required depth is reached.

It was claimed that four boats equipped in this way could make and keep open a channel 10 or 12 ft. deep between St. Louis and Vicksburg.

(12) An "excavator," similar to that described in Section 10, is attached to the bow of a boat, and has vertical shafts with scrapers at the lower end which are revolved by means of belts. The depth of the shafts is regulated by a screw at the upper end of each. This device also relies on the current to carry off the loosened material. The inventor says that "The revolving cutters cut up the material and churn and stir it to a considerable extent, so that it will be carried away by the current."

(13) Another "channel plow" inventor has a device which he claims will produce:

"A mean smooth bottom, circular in form and non-resisting, which will be of sufficient width and depth to contain and carry off within banks the greatest floods, resulting in the disappearance of all snags, sawyers and bars."

It will "Provide a steady flow of tranquil waters at all seasons and stages." It will cause a "Total cessation of overflows and the consequent reclamation of many river-bottom lands, and that, too, without the aid of levees."

This, certainly, covers the whole ground. The earnest efforts of all hydraulic engineers interested in river improvement are directed toward the accomplishment of the results set forth, but none of them are as confident of success as the inventor seems to be.

(14) One of the latest devices offered, to solve the problem of removing sand bars, is made in the form of a conveyor such as used in mills and elevators, but, of course, much larger in size. This spiral or screw has blades several feet wide, attached to a hollow shaft, and is made up in sections 10 ft. in length. These sections are strung on

a steel spindle until the whole screw is of sufficient length to reach across the bar. To utilize this device, it is dropped down over the bar, and, when in proper position, it is held in place by means of anchors or piles connected with wire cable to the upper end of the spindle. It, of course, trails down stream parallel to the current, and the pressure of the current against the blades causes the screws to rotate. In this way the sand is loosened up and conveyed to the pool below the bar.

All the power required in this case is derived from the current, and as the screws themselves are comparatively inexpensive, this would be a very economical method of cutting down bars if the inventor's ideas of efficiency were realized.

(15) A simple arrangement, intended to make each boat independent of outside aid when shoal water is encountered, is that in which the hull of the boat is provided with wings, which, when not in use, fold closely against the sides. On approaching a shoal the wings are opened and a portable dam is thus formed which raises the water; and this, in addition to the pressure on the wings, enables the boat to ride safely over what would otherwise be an impassable barrier.

(16) The "automatic sand dredger" consists of a stern-wheel boat to which is attached a horizontal shaft bearing a number of cutting disks, constituting a dredging wheel. The extremities of this wheel shaft are connected by bars to a shaft extending across decks near the bow of the boat. A convenient hoisting drum serves to raise and lower the cutter. The cutter has considerable weight, and the hooked cutters penetrate the sand, which is loosened and lifted up where the current catches it. As the boat is moved over the bar with the cutter lowered, the cutter wheels roll along the bottom.

(17) Another scraping device consists of a suitable boat provided with two long parallel booms or spars across decks about amidships. These booms project about 50 ft. out from the sides of the boat. The ends of the booms are braced and are supported by guy lines leading to a central mast, and also a second pair of guys leading to the bow and stern of the boat. The wings are hinged on each side of the boat to the forward boom. They extend from the side of the boat out to the end of the boom, and are wide enough to reach the bottom when let down on a bar which it is desired to deepen. The lower edge of these wings is weighted and provided with teeth or plows which pene-

trate and stir up the material. Guy lines, leading from the lower edge of the wing to winches on deck, serve to hold the teeth in contact with the bottom. When not in operation the wings are lifted up flush with the deck by means of tackle attached to the rear boom.

In operating this device, the boat moves down stream over the bar, carrying the sand with it over the reef. The current acting on the wings helps the boat along. This operation is repeated until the desired depth is secured.

(18) Another device is a "dredging machine" for use in "working out the channels of rivers and in removing sedimentary formations from the beds of running streams." The agitators are called "wipers." These agitators are attached to the stern of a side-wheel boat and are operated by means of bevel gears so arranged as to revolve the wipers in opposite directions. They are hung on a cross-shaft which admits of their being raised or lowered. The wipers are made with spiral flukes, so that the lower points will enter the deposit first and then draw it upward, thus lifting it from the bottom, and disintegrating it so that the current can carry it away. The number of agitators will depend on the magnitude of the work. The boat is to be moved back and forth over the bar, with the agitators at work, until the required depth has been obtained.

(19) A ship's drag for dredging rivers is a device to be attached to a steamboat or barge and dragged over the bar to be deepened. The teeth rake and stir up the bottom to such an extent that the current carries the material away. The teeth of the drag are rounded in front and have a groove in the back. The object of this groove is to form an eddy and thus aid in keeping the matter in suspension until the current takes it up. The frame holding the teeth can be separated into several jointed parts by means of hinges, and in this way the scraper will conform to the shape of the ground over which it moves.

Current Deflectors.

(1) The most pretentious of current deflectors is a "Machine for Deepening River Channels," invented in 1879. The object of this machine is to "deflect the current of a river downward, and thus cause the said current to deepen the channel." This consists of a boat to which is attached a triangular box which can be lowered to a point near the bed of the stream, the axis of the box being at right angles to

the boat and to the current. The up-stream edge of the box has flanges for regulating the flow.

In operating this machine it is moved across the bar, either up or down stream. The current strikes against the inclined side of the box and is thereby deflected downward, which causes it to impinge against the bed of the river and wash away the sand to a considerable depth. In case the bed is composed of clay not easily abraded, it is first loosened by means of a revolving toothed cylinder, and then carried away by the deflected current. The boat is held in position against the current by means of arms pivoted to the sides, the lower ends resting on the bottom. A wheel in front of the device is of sufficient diameter to show above water when resting on the bottom. The object of the wheel is to bring up samples of the bottom of the river so that the "engineer may know the exact kind of bottom there is at each point," and conduct his operations accordingly.

The device is further provided with a graduated disk attached rigidly to the arms supporting the triangular box. To the center of the disk is pivoted a weighted pointer which will always hang vertical and hence show the inclination of the box supports and consequently the depth of water. The inventor also provided an automatic recording device which would plat the profile of the bottom as the boat passed over it.

In moving from one bar to another the deflecting box is to be raised above the surface of the water by means of lines attached to the rear arms. Just how this is to be accomplished is not clear.

(2) Another device for deflecting the current downward on the bed of the stream is styled a "dredger," and is described as a "simple, inexpensive and efficient device for deepening the channels of rivers, removing sand or mud therefrom and for preventing the formation of sand bars." These desirable results are accomplished by means of several parallel plates of different lengths which are set at an angle with the vertical, but having the lower edge of the plates in the same plane. These plates are securely held in a suitable frame, and the whole is supported on short legs.

This frame, with the attached plates, is set on the bottom of the stream with the plates inclined up stream. The current, in striking the plates, is deflected downward, and thus produces a scouring effect on the bottom. When sufficient depth has been secured it is moved

to a new position. The size and number of these devices to be used is, of course, governed by the magnitude of the channel desired. The device is to be handled from suitable boats or barges. A device similar to this was used in the improvement of the South Pass with some success.

If it is desired to erode a bank the device is turned on edge so as to throw the current against the bank. To prevent the formation of sand bars, this inventor says that all that is needed is to suspend near the bottom V-shaped plates with perforations at the angle. The current caught by the open arms of the plate will escape through the perforations with force enough to keep the sand on the move.

(3) Another "device for regulating the flow of streams," deepening the channels and removing obstructions is also intended to deflect the current downward against the bottom. It consists of a frame having a suitable number of cross-bars to divide the interior space into cells of proper size, depending on the magnitude of the stream. The upper surface of the frame and cross-bars are filled with teeth, which, together with the cells, obstruct the even flow of the water and produce a "violent suction or eddy in the current." This increases the momentum or gravity of the water and causes it to "force itself violently" through the orifices between the cross-bars and thus churn up and wash away the bed of the river. In this way the sediment composing the bottom is agitated to such an extent that the stream is compelled to take it up and carry it away in suspension.

The device can be made in any number of sections joined together by chains and anchored to the bottom of the river. In this way, it is said, bars can be prevented from forming and the bed of the river can be depressed to any desired extent.

It is perhaps well to note here that the principle involved in the foregoing devices, and which is relied upon to erode the bottom, is to be found in several other devices where it is expected to induce deposit. If the current can be deflected downward and erosion produced, then a barge anchored over a reef should produce similar results, as the current striking the end rake would be deflected downward. In practice, it is a well-known fact that a barge anchored in shallow water will very soon cause the sediment to deposit. In dredging, the plant is never left in the cut for any great length of time when the pumps are not in operation. If a break-down occurs which necessi-

tates extensive repairs, the plant is swung out of the cut so that the current may have free access to it.

Nearly all the current deflectors proposed are intended to deflect the current laterally, and for this purpose inventors have brought out jetties of various kinds.

(4) A simple and efficient jetty deflector is made by driving piling along the desired line at intervals of about 20 ft. On the up-stream side of the piling small flat boats 16 by 40 ft. in size are lashed in a continuous row. Corrugated steel aprons 10 x 10 ft. in size are hung over the upper side of the flats at a considerable angle with the river bed, to allow for straightening up as the bottom scours out. The corrugated sheets of steel are stiffened by three angle-bars of 3 x 3-in. section firmly riveted to each sheet. The jetty is also constructed without the boats by attaching to the piling a stringer on which the plates are hung.

This jetty has been used with success between the Missouri and Ohio Rivers. Twelve hundred feet of jetty was built in one locality in four days with a force of twenty-two men. It cost about $2 per running foot. The effect was almost immediate. The water was deepened from 4 ft. to 7 ft. with a fall of 1 ft. in the stage of the river.*

A similar jetty has been proposed with the substitution of canvas for the steel plates and omitting the use of the flats. In this device it is proposed to make a curtain of canvas, say 15 ft. wide and 100 ft. long; one edge and the seams to be reinforced by sewing in hemp rope of suitable size with good lashings at the edge. At the other edge a chain is to be lashed to the canvas as a sinker. The whole is rolled up like a reefed sail. In order to use it, the piling is driven as before. The roll of canvas is stretched across the up-stream side of the piling above water and lashed at each pile. When everything is ready the reef lashings are to be cut and the weighted edge causes the canvas to unroll and sink to the bottom. The flexibility of the chain insures a close contact with the bottom. As many lengths of curtain can be used as may be found necessary.

(5) Similar deflectors are made portable by means of double-hull boats which admit of dropping sheet-piling down between the hulls. When it is desired to deflect the current, or cut off a side chute, a num-

* Report of Chief of Engineers, U. S. A., for 1896.

ber of these boats are placed in position, end to end, until sufficient length is obtained. These are known as the King jetties.

(6) Another way of accomplishing the same result is by means of steel barges of suitable length, known as the Marsh jetties, which are designed to sink by filling with water. The ends are wedge-shaped and the sides are straight, so that one boat may be lapped and fastened to the next, and so on until sufficient length has been obtained. In this way the current will be effectually deflected to the channel which requires deepening.

When the desired results have been obtained the water is pumped out of the hulls, which are thus floated and are then ready for another bar (see Fig. 4).

(7) Another inventor, somewhat earlier than the last named, hit upon a wooden sinkable deflector and plow, by means of which the "Sand,

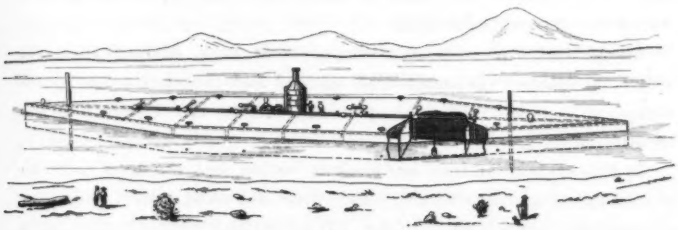


FIG. 4.

sediment, etc., at the bottom of the river will be sufficiently irritated to enable the current to carry it off." The jetties consist of strong wooden boats triangular in cross-section, the apex of the triangle forming the keel. These boats are designed to be from 500 to 600 ft. long. The plan would also be triangular, the greatest width being in the middle and then tapering off toward each end, which terminates in a strong timber head. The upper portion is open, with occasional cross-bracing. In order to use this jetty it is towed to the point desired and then sunk by filling it with water.

In order to secure the required length several may be sunk with a slight overlap. In this way the current is supposed to be deflected so as to cut out bars, or even make a cut-off if required. When the work is done the jetties are floated by pumping out the water. It is claimed that they can be "raised and removed in two hours."

An attachment termed a plow is applied to the towboat which handles the jetties. Its function is to loosen up the hard material so that the current from the jetties can get hold of it and carry it away. This plow can be raised or lowered at will, by suitable winches which are provided for that work. It is claimed that by the use of these devices rivers can be plowed to a depth of 30 ft.

(8) Some inventors have directed their energies toward the use of material at hand. One of the earliest of this kind of deflector was made of huge trees with branches intact, and sunk in the desired place by means of heavy weights attached to the butts, while the tops were free to take the direction of the current. A row of such trees are sunk side by side, and, if need be, others are added on top. This is not intended to stop the flow to such an extent as to form eddies, but sufficient to silt up the stream at or below the dam and deflect the water to the desired channel, and cut out the bar against which the current is directed.

(9) Another inventor uses similar trees in a different manner, which he claims "Is founded on natural and therefore correct principles, to correct, widen, deepen and confine the channels of the rivers."

In this system the trees are sunk as before, but the tops must be placed up stream to catch the small drift and sand, which very soon accumulates and fills up the dike. The trees may be held in place with piling. This jetty is intended to induce rapid deposit, which soon forms around the trunks of the trees, "Firmly anchoring them to the bottom; the branches are next surrounded and covered by sand, completing by a natural process the indestructible and impregnable dam."

Water-Jets and Auxiliary Devices.

Several jet devices have been proposed which aim to make each steamboat independent of any general improvement of the channel by providing suitable jets which will enable the boat to work its own way through the bars.

(1) One of these jet devices consists of two double-acting pumps which force water through twenty-eight 3-in. nozzles arranged symmetrically about the bow of the boat. On reaching a shallow bar, the force pumps are started, the jet valves are opened, and the boat is pushed ahead as the sand yields to the eroding force of the jets. In this way

the boat carries a pool with her across the reef, and at the same time will probably improve the depth for the boat that follows.

(2) Another device aimed to accomplish the same result with a different kind of pump and a different arrangement of the jets. It was claimed for this invention that its use would make channel improvements with dredges, contraction or other means entirely unnecessary. By this scheme each steamboat was to be equipped with a centrifugal pump with a capacity of about 2 000 galls. per minute. The discharge pipe was designed to run the whole length of the hull along the center truss. The jets emanating from this pipe were arranged to discharge along the lower line of the hull directly on the sand. The jet nozzles were arranged so that they could direct the stream either forward or backward, so as to always act with the current, whether the boat were going up stream or down.

When the boat reached a bar the pump was to be started and the jets opened, the boat being constantly forced ahead until finally carried over the reef. The estimated cost of this attachment was only $3 000 for each boat, while the cost of delays in a single trip caused by grounding might readily exceed this amount.

In urging the utility of this method the inventor makes the following statement:

"It cannot be expected that the Government will every year spend thousands of dollars to remove sand bars which re-form at every flood. Those interested in river navigation ought to make themselves independent of such obstructions and of Government aid, but they will not entertain the idea until forced to."

Admitting that these devices would enable a single boat to force its way through obstructing sand bars, there still remains the great bulk of traffic, which moves in barges that cannot be carried over by the methods proposed.

(3) Another jet device, intended to remove the obstructing bar, is called a "Submarine plow or hydraulic apparatus for removing sand bars." It consists of several jet pipes fixed to a drag frame which is pivoted to the bow or stern of a suitable boat. Each pipe terminates in three jets, one of which points downward and loosens the material, while the other two are bent so as to pick up the loosened material and carry it upward where the current will take it and move it along. The combined force of the current and the jets carries the particles of sand some distance before they come to rest. The curve of each jet

pipe is filled in with a web, so that if it strikes a log or other obstruction it will slide over it without catching. The whole device is provided with tackle and winches conveniently arranged to raise or lower the jets, and suitable pressure pumps supply the necessary water.

It is claimed that a vessel with a 500-H.-P. equipment of this kind can erode a depth of 5 ft., taking out a cross-section of 27 sq. ft., at the rate of 6 miles an hour, throwing the sand and gravel to the surface in 30 ft. of water.

This device was used in Gedney's Channel, New York Harbor, but was abandoned on account of the slack current at ebb tide and the influx of material at flood tide.

(4) Water-jets were used with marked success on Horse Tail Bar, near St. Louis, in 1881. Four pile-drivers were lashed two abreast with their heads together. Each one of these drivers was equipped with a Worthington duplex pump with a 7½-in. steam cylinder and a 4½-in. water cylinder having a 10-in. stroke. The capacity was about 165 galls. per minute each. The four jets were brought together. Anchors were laid and the drivers were pulled back and forth across the reef with a steam windlass, all the pumps working in the meantime to their full capacity. In ten hours' actual work in this way the channel was deepened from 6 ft. to 8.3 ft. for a width ample to pass the largest tows.

(5) In 1896 a jet dredge was constructed under the supervision of Major Thos. H. Handbury, for the work between St. Louis and Cairo. The main features are two 15-in. centrifugal pumps driven by direct-connected 15 x 14-in. engines. The steam is furnished by two 4-flue boilers 28 ft. long with 42-in. shells. This machinery is mounted on a suitable barge.

The suctions lead over the sides of the barge, and the discharge leads over the bow. The capacity is 20 000 galls. per minute. This water is forced, through four 12-in. discharge pipes with flattened nozzles, against the sand, which is thus stirred up and washed into deep water. The attack is from the up-stream side of the bar, and the boat is dropped down, with jets in operation, until the lower pool is reached. This operation is repeated until the desired depth is obtained. The plan and elevation of the bow of this jet dredge are shown in Fig. 5.

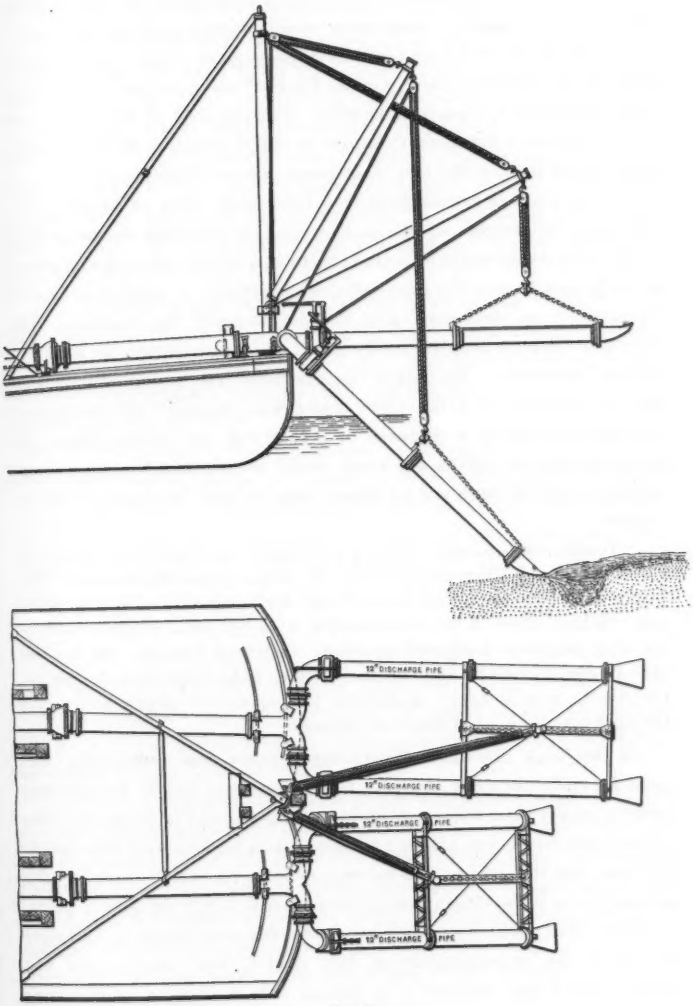

12" DISCHARGE PIPE
12" DISCHARGE PIPE
12" DISCHARGE PIPE
12" DISCHARGE PIPE

FIG. 5.

On short reefs, this device is reported to be quite efficient. Where the reefs are of considerable length the accumulation of sand in front of the jets becomes too great to be moved economically in this way.

(6) By far the most pretentious improvement scheme by means of jets, yet proposed, is the "Adams Flume," the construction of which was authorized by Congress in 1879. The purpose of this device was to "Establish a permanent channel in the Mississippi River from St. Paul to the Gulf of Mexico," a distance of some 2 000 miles.

It consisted of a triangular iron tube with sides of about 12 ins. The different lengths of this pipe were provided with flanges at both ends, so that they could be bolted together, a rubber gasket being placed at each joint to give the pipe sufficient flexibility to adapt itself to the undulations of the bottom and the curvature of the channel. The pipe was divided longitudinally into two compartments by means of a metal partition. The lower compartment was provided with ½-in. jets at intervals of 1 ft. Clear water was pumped into the upper compartment under a pressure of 5 to 8 lbs. per square inch. By means of suitable valves the water could be let into the lower compartment and through the jet pipes; then, in the language of the inventor:

"It stirs up the sand, holding it in suspension till the current carries it off to some low place where it forms banks like a canal. The number of jets to be opened at any time is governed by the pressure. Where there is any obstruction it is opened on like a battery; no sand, gravel or moderate hard-pan can stand near it. To lay this pipe in one unbroken line in the center of the river from its head to the Gulf, it will scour a channel the necessary depth and width throughout and keep it open all through."

In this work one small Worthington pump was considered sufficient for each 100 miles of pipe. Clear water was said to have greater eroding power than water containing sediment, and in order to secure it, the river water was allowed to flow into a tank or well attached to the boat and the pump took its supply from the well. Just how the sediment was to be eliminated by this process is not altogether plain.

More than eight years and about $40 000 were spent in attempts to prove the practicability of this device, but the project was finally abandoned without ever laying a foot of pipe in the river channel. This large waste of time and money cannot be charged to the engineers, for Congress, through the Secretary of War, dealt di-

rectly with the inventor, the law requiring that the device should be made and tested under his supervision and direction. For five years the "preliminary arrangements" were going on, the expenditures having reached the sum of $27 500. One locality after another was agreed upon as suitable for the trial, but there was always something to prevent an actual test. Another appropriation of $15 000 was made, and the "preparations" were continued for several years more without results of any kind. A board of engineers was then appointed to examine and report on the advisability of continuing the experiments. Their conclusions were that it could not be successful even on a small scale.

The engineer officer in charge of the district was instructed to take charge of the work pertaining to the flume. The only thing found to show for the $40 000 was a small amount of sheet-iron pipe made for experimental purposes, and little or none of this was completed and ready for use.*

(7) The removal of bars by means of blasting has been tried, but with unsatisfactory results. Torpedoes, loaded with 75 to 160 lbs. of powder, have been exploded at depths of 10 to 20 ft. below the surface of the sand, but the results have invariably proved disappointing. Large quantities of powder in tin canisters laid on the crest of the bar have been exploded without materially improving the channel depth.

In the foregoing pages the author has attempted to give a brief account of various devices which have been offered to solve the difficult problem of improving the low-water navigation of the Mississippi River. A few of the devices have been actually used, and still fewer have been moderately successful.

The Long scrapers used on the upper Mississippi some 28 years ago were pronounced satisfactory, although the best they could do was to increase the depth over short reefs 12 to 18 ins. About this time the use of temporary expedients gave place to a system of permanent improvements, consisting of the closing of chutes, the contraction of wide places by means of jetties or dikes, and the revetment of banks. The inauguration of this policy, to the exclusion of temporary expedients for channel improvement, was evidently a mistake, due probably to the fact that the length of time required by the so-

* Report of Chief of Engineers, U. S. A., 1888, p. 1488.

called permanent method before tangible results could be realized was very much underestimated.

In the meantime, competition of railway lines along the banks of the river, and difficulties of navigation, threatened to annihilate the river traffic. Steamboat men saw their profits dwindling, their business gradually dying out, and they urgently appealed for relief. They could not wait for the completion of permanent improvements. Immediate temporary relief must be found, or the river as a great commercial highway must be abandoned. It was in response to this appeal that temporary channel improvements were again taken up and were finally, after several years of agitation, made obligatory by Congress, for the lower river, in the River and Harbor Bill of June 3d, 1896.

In the expedients which were tried or suggested for temporary improvement of the channel, and which have been described in the preceding pages, the chief defect lay in relying on the current to carry off the material after it was loosened up. It was generally thought that if the crest of a bar was thoroughly loosened up, the current would carry the material away, and thereby the depth would be increased. Engineers very soon saw that but little additional depth could be gained in this way.

River men still talk of a "crust" on a sand bar, and believe that it prevents erosion by the current until broken by scrapers or other means, and that after this is done erosion is rapid and effective. One of the members of this Society was probably among the first to recognize the necessity of carrying the spoil out of the channel by artificial means. In 1870, after experimenting with dipper dredges for some time, Robert E. McMath, M. Am. Soc. C. E., reached the conclusion that:

"The successful use of sand pumps and hydraulic conveyors and distributors of débris inclines me to the opinion that a combination is possibly better adapted to the work of river improvement than any means yet used."

In 1883 a plant was provided for dredging in the Mississippi River above the mouth of the Illinois River. This plant consisted of an Osgood dipper-dredge and six dump-scows, the whole plant costing $29 348. It was used with good results. The first work was done at Howard's Bar, near La Grange, Mo., where a channel was opened 1 000 ft. long, 110 ft. wide and 5 ft. deep. It was completed in about

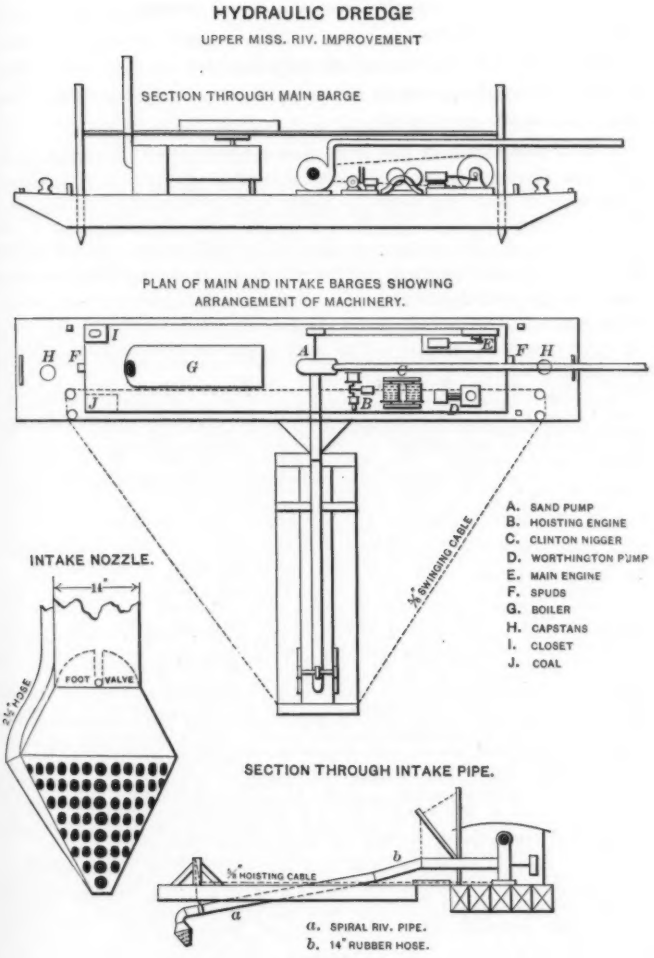

HYDRAULIC DREDGE
UPPER MISS. RIV. IMPROVEMENT
SECTION THROUGH MAIN BARGE
PLAN OF MAIN AND INTAKE BARGES SHOWING ARRANGEMENT OF MACHINERY.
A. SAND PUMP
B. HOISTING ENGINE
C. CLINTON NIGGER
D. WORTHINGTON PUMP
E. MAIN ENGINE
F. SPUDS
G. BOILER
H. CAPSTANS
I. CLOSET
J. COAL
INTAKE NOZZLE.
14"
FOOT VALVE
SECTION THROUGH INTAKE PIPE.
a. SPIRAL RIV. PIPE.
b. 14" RUBBER HOSE.

FIG. 6.

a week, and the channel remained open throughout the season. Part of the material was removed by dump-scows, but the greater part of it was dropped beside the cut, which was located parallel to the thread of the current.

This plant was also used at other places with good results. Major Ruffner, the engineer officer in charge, in the following words, recognized the utility of dredging :*

"The experience of the past season has shown that much assistance can be given to navigation by this kind of work, which, though temporary in a certain sense, is likely to be permanent for one season if not longer. * * * By the temporary use of dredges, at an expense so comparatively small as to be fully justifiable, I have no doubt a good navigable channel can be maintained during the low-water season on this stretch of the river, and if the navigation of the river is to be continued with success by steamboats, such temporary aid must be given until such time as the permanent channel improvement is completed."

In 1887 a contract was entered into for a hydraulic dredge and decked flat-boats to support 500 ft. of discharge pipe, to be used in the district above named. Experience had shown that a dipper dredge could do good work under favorable conditions, but for opening temporary channels through bars it was found to be too slow in its operations and hence too expensive. A dredge provided with a centrifugal pump for pumping sand and water from the channel and delivering the same through pipes far enough away to clear the channel was manifestly an improvement on the old method with bucket-dredges and dump-scows (see Fig. 6). This hydraulic dredge was equipped with a Van Wie No. 12-pump, with a 14-in. intake and a 12-in. discharge. The pump was run at the rate of 330 revolutions per minute and the material was lifted about 9 ft. above the surface of the water and discharged from 300 to 800 ft. from the pump. The intake nozzle was provided with a jet supplied by a Worthington pump, to aid in stirring up the material so that the suction could take hold of it.

The steam plant consisted of one boiler 22 ft. long, and having a 42-in. shell with ten 6-in. flues. The main engine was of the Wright and Adams pattern, 14-in. cylinder and 18-in. stroke. There was also a hoisting engine and a "nigger engine," each having 6 x 8-in. double cylinders.

The intake pipe is supported by a double pontoon, or two barges 4 by

* Report of Chief of Engineers, U. S. A., 1884, pp. 1561-1567.

50 ft., framed together with a 4-ft. space between them. The dredge end of this pontoon is pivoted to a triangular brace attached to the dredge, and the outer corners of the pontoon are connected with the dredge by means of wire cable-guys, passing through sheaves to the "nigger engine," which serve to swing the pontoon, with the suction, around in a semi-circle with a radius of 48 ft. A hoisting cable serves to raise and lower the suction between the two parts of the pontoon. The intake pipe has a 14-ft. length of rubber that connects the iron pipe of the suction with the iron pipe from the dredge to give the pipe sufficient flexibility. All engines are located so as to be handled by one man.

The machinery is mounted on a wooden hull 20 ft. wide, 100 ft. long and 4 ft. deep, and is housed in by a suitable cabin. There is a spud 12 ins. square at each end of the dredge which serves to hold it in the desired position. There are a number of small flat-boats 12 by 32 by 2 ft., each of which carries 45 ft. of discharge pipe. The several lengths of pipe are connected together with rubber hose. The flat-boats are coupled together by triangular wooden frames bolted to the decks, and so arranged as to couple with an iron pin midway between the boats. The discharge pipes are carried on a frame erected so as to give a slope of about 1 ft. in 100 ft.

This dredge is manipulated by means of two head lines anchored well up stream, and the dredge is moved and kept on line by swinging first on one spud and then on the other, alternately. The work can be done either with or against the current, each cut being about 90 ft. in width. The dredge is moved about 8 ft. at a time. A vacuum gauge at the suction side of the pump and a pressure gauge attached to the discharge side serve to show the operator whether the pipes are obstructed or whether the proper proportion of sand is being carried. This dredge delivers from 3 to 7% of sand through 600 ft. of discharge pipe at the rate of 70 to 100 cu. yds. per hour. It requires a crew of 7 men, costing $355 per month, to operate the dredge. The cost for 90 working days, including delays of all kinds, and the current repairs, was $2 928.71. During this time the dredge removed 42 900 cu. yds. of sand, at a cost of 6.8 cents per yard.

It is used not only to deepen channels, but also to fill in dikes and dams. This is quite an advantage where the amount of sediment carried by the stream is small.

This plant has been operated by Assistant Engineer J. Du Shane, and the above description is largely drawn from his report on the plant, which, together with other data, was obtained by the author from the U. S. Engineers located at Rock Island. The description here given applies to the dredge as remodeled in 1895.

This dredge evidently was regarded as fairly successful in that part of the river where first brought into use, as Major Ruffner, then in charge, says:*

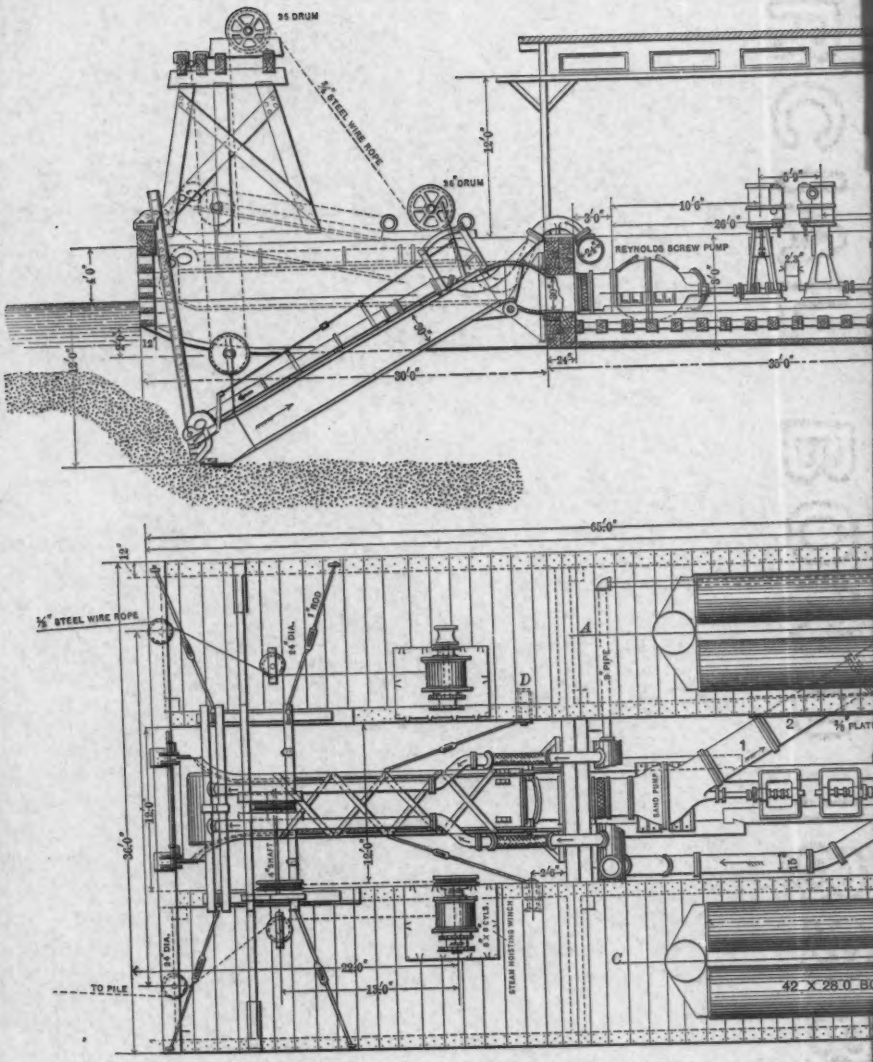
"I believe that patience and some mechanical skill will make our machine able to dig a channel through any of our ordinary bars here, deep enough to induce the main flow of water through it in three days' work. * * * If this can be done there would be no difficulty in opening and maintaining a good navigable channel through this stretch of the river (between the Des Moines and Illinois Rivers) when the water is falling, by the use of two or three of these hydraulic dredges constantly operating and moving from the worst bar to the next one needing dredging."

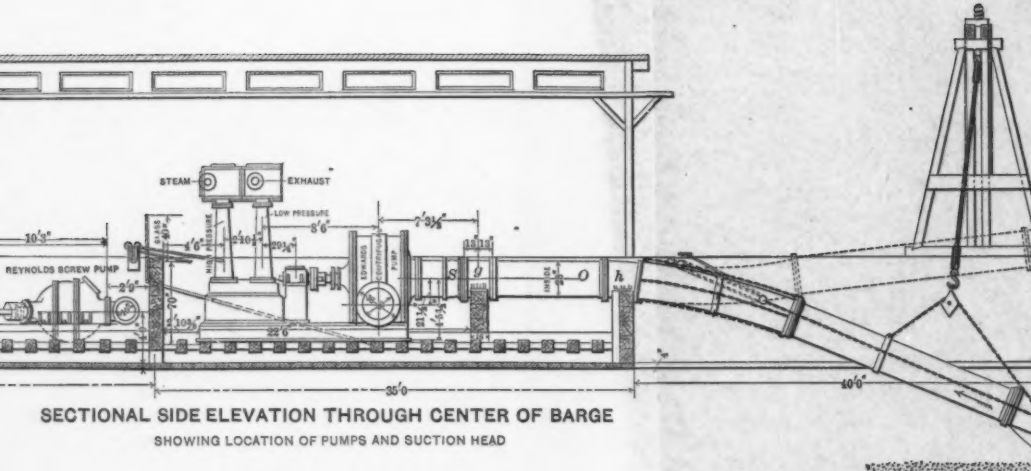
While this dredge was evidently a move in the right direction and was very useful in the upper river, its capacity was entirely inadequate to meet the requirements of the lower river. Here the dredging required at a single bar often exceeds 100 000 cu. yds., and the time permissible to remove this large amount of material is very short. To successfully accomplish this result, machines were required of far greater capacity than any heretofore used or known.

In November, 1891, the representatives of steamboat transportation lines below St. Louis appeared before the Mississippi River Commission and urged immediate relief for low-water navigation. They stated that if such relief depended on the completion of the permanent improvement work, by the time it came, there would be no traffic. In response to this appeal, the Commission appointed a committee of two:

"To study the subject of the construction and operation of such appliances for dredging as can be applied to the deepening of the Mississippi River over the bars in extreme low water;" * * * and "Prepare and report a project for the construction of a dredging boat of as large capacity as can be handled in the channel of the Mississippi River at low water with safety and convenience."

* Report of Chief of Engineers, U. S. A., 1887, p. 1614.

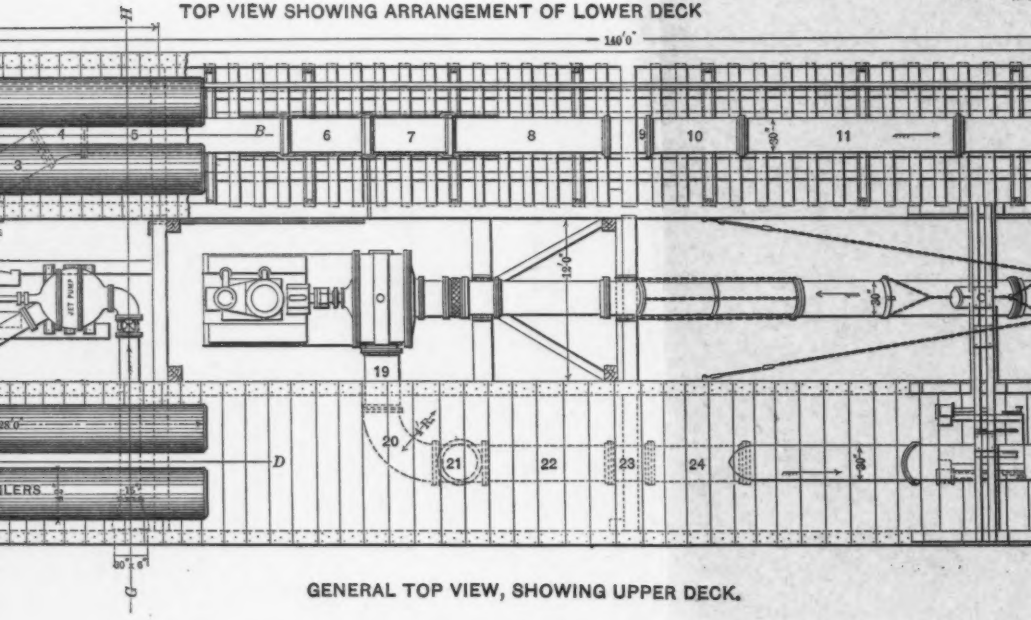

25 DRUM
⅝" STEEL WIRE ROPE
25" DRUM
REYNOLDS SCREW PUMP
⅝" STEEL WIRE ROPE
70 FILE
42 X 28.0 BO



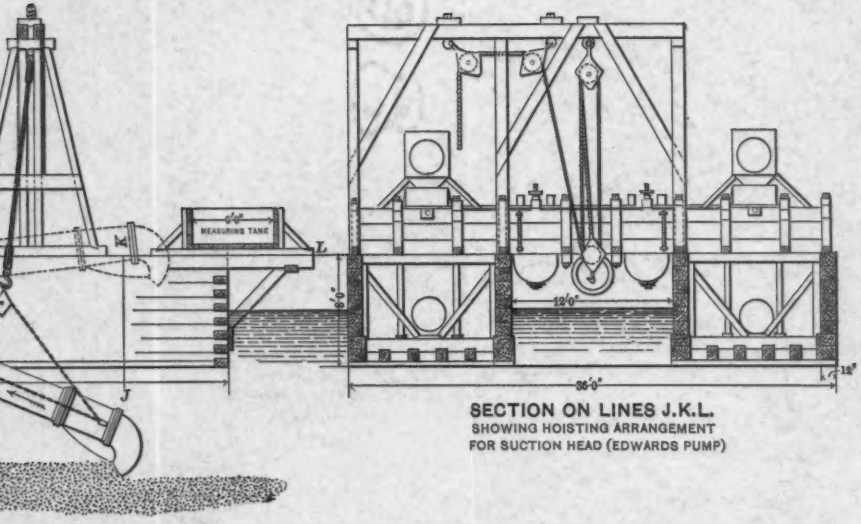
SECTIONAL SIDE ELEVATION THROUGH CENTER OF BARGE

SHOWING LOCATION OF PUMPS AND SUCTION HEAD

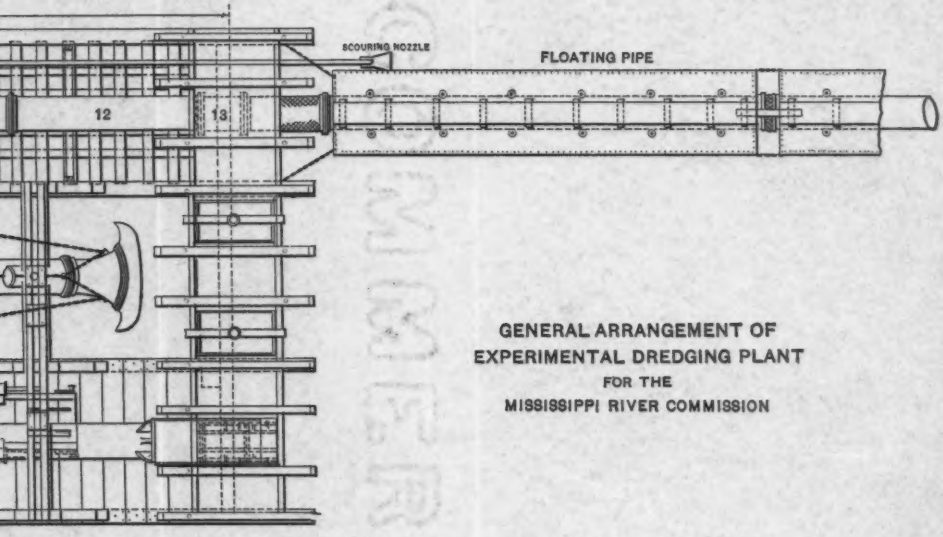
TOP VIEW SHOWING ARRANGEMENT OF LOWER DECK



GENERAL TOP VIEW, SHOWING UPPER DECK.



SECTION ON LINES J.K.L.
SHOWING HOISTING ARRANGEMENT
FOR SUCTION HEAD (EDWARDS PUMP)



GENERAL ARRANGEMENT OF
EXPERIMENTAL DREDGING PLANT
FOR THE
MISSISSIPPI RIVER COMMISSION

It should here be stated that the law under which the Commission were operating required them to prepare a plan to permanently locate and deepen the channel, and hence temporary expedients were naturally omitted from their plans up to this time.

Colonel Chas. R. Suter and Henry Flad, both Members of this Society, were designated to serve on this committee. After a thorough investigation of the matter, the committee concluded that among the various devices for temporary relief, dredging was the only means which held out a reasonable promise of success. The problem involved so many new features in the way of the enlargement and combination of devices heretofore used, that the construction of an experimental dredge was recommended. Drawings and specifications were prepared under the direction of this dredging committee, for an experimental dredge, and contracts for the construction of the various parts were let, at the close of 1892.

This experimental dredge was equipped with an Edwards centrifugal pump having a curved drag-suction at one end, and an Allis-Reynolds screw pump having a straight suction with jet agitators at the other end, the object being to make practical tests of the efficiency of the different devices. The pumps, engines and boilers were designed by their respective manufacturers. The Edwards pump runner was 6 ft. 4 ins. in diameter, and was operated by a compound, non-condensing, vertical engine with cylinders 15 ins. and 27 ins. in diameter, respectively, and with 20-in. stroke. The suction and discharge were each 30 ins. in diameter. The Allis-Reynolds pump was operated by a compound non-condensing vertical engine, with cylinders 8 and 16 ins. in diameter and with 12-in. stroke. The suction and discharge pipes were each 30 ins. in diameter. The jet pump was of the Allis-Reynolds pattern, with suction and discharge 15 ins. in diameter. This pump operated six jets $2\frac{1}{2}$ ins. in diameter under a head of about 20 ft. By this means the material was loosened and divided up so as to enter the suction of the sand pump thoroughly mixed with water.

The steam for the various pumps, etc., was supplied from four boilers 38 ins. in diameter and 28 ft. long, of the type in common use on Mississippi River steamers. Hoisting apparatus was also

provided for raising and lowering the suction and moving the dredge.

The above-described machinery was mounted on a wooden hull 130 ft. long, 36 ft. wide and 8 ft. in depth. The dredge in working order drew about 4 ft. of water. A good general idea of this dredge can be obtained by inspecting Plate XXIV.

The material pumped was discharged through a floating pipe line made up of sections of pipe 33 ft. long, connected by means of strong rubber joints and iron coupling bars. An air chamber on each side of the discharge pipe served to float it when loaded with 10% or less of sand. In order to operate the dredge, two hydraulic piles are set about 25 ft. apart, near the upper end of the bar to be excavated. A wire rope about 1 000 ft. long is attached to each of these and to the hauling drums on the dredge. If the wind does not deflect the dredge from its proper place, it is allowed to swing freely in the current with the discharge pipes trailing below it. If necessary, side piles are set, and by means of lines attached to them, the dredge can be hauled into such position as may be desired. In dredging, the boat is pulled ahead up stream at rates varying with the depth of the material taken out, the average movement being about 60 to 75 ft. per hour. After one cut is finished, the dredge is dropped down again to the lower end of the bar, the head piles are moved over about the width of the cut and another cut is made near by and parallel to the first. This process is repeated until a channel of the required width and depth has been secured.

There is perhaps no single feature which facilitates this method of dredging as much as the hydraulic mooring piles (Fig. 7). The ease with which they can be set and withdrawn, and their great holding power, make them really indispensable where dredging is done in strong currents. They are sunk 15 or 20 ft. deep in the sand, and the head lines are attached to a shackle down at the surface of the sand, and consequently there is little danger of bending. A pile sinker provided with suitable leads and hoist, pumps and boilers, is required with each dredge. The pile is open at the lower end for the full size of the pipe. On the side of the pipe near the upper end is an opening 2½ ins. in diameter to which the pressure pipe from the pump is attached. The ease with which piles can be set and withdrawn is clearly set forth in Table No. 1, page 250.

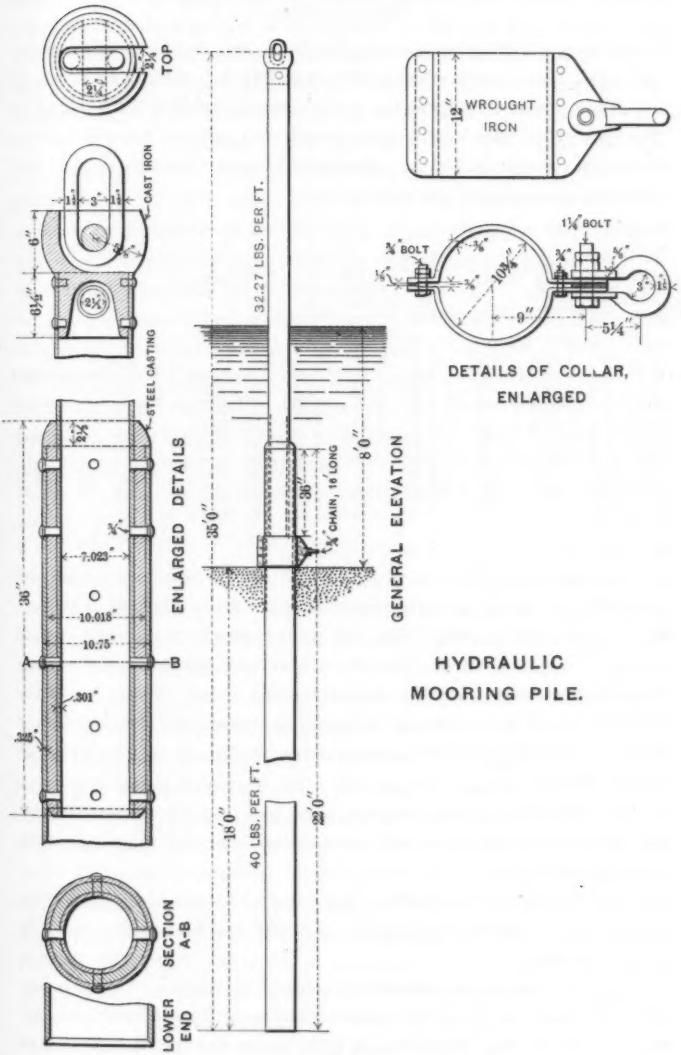

TOP
CAST IRON
STEEL CASTING
ENLARGED DETAILS
LOWER END
SECTION A-B
32.27 LBS. PER FT.
40 LBS. PER FT.
CHAIN, 16' LONG
GENERAL ELEVATION
WROUGHT IRON
1¼" BOLT
¾" BOLT
DETAILS OF COLLAR, ENLARGED
HYDRAULIC MOORING PILE.

FIG. 7.

TABLE No. 1.—EXPERIMENTS IN SINKING HOLLOW WROUGHT-IRON PILES IN SAND.

In these experiments one 6-in. inside-packed, double-plunger pump was used. The length of the piles was 34½ ft.; outside diameter, 11 ins.; thickness, $\frac{3}{4}$ in. for the heavy piles, which weighed 3 250 lbs. each. The light piles were of the same length and outside diameter; thickness, ½ in.; weight, 2 370 lbs. Diameter of water-pressure inlet 2½ ins. The piles were open at the bottom.

Number of test.	Depth of water.	Depth of penetration.	Pressure required.	Time required to sink.	Pile left undisturbed.	Time required to raise.	Boiler pressure.	Kind of pile.	Remarks.
	Feet.	Feet.	Lbs.	M. S.	H. M.	M. S.	Lbs.		
1..	6.0	19.5	40	3 46	1 05	1 12	70	Light	Both hoist and pump used to draw.
2..	7.5	19.5	40	3 34	1 15	1 35	65	Heavy	
3..	7.0	19.0	35	4 53	1 30	1 20	60	Heavy	Hoist only used to draw pile.
4..	8.0	20.0	35	6 00	1 50	1 35	73	Light	
5..	8.5	19.0	30	6 00	0 35	1 13	70	Heavy	Both hoist and pump used.
6..	8.0	18.0	30	4 29	16 00	1 25	68	Heavy	
7..	12.0	19.0	30	3 23	16 00	1 26	74	Heavy	
8..	12.0	18.0	35	3 26	1 55	1 11	68	Heavy	Hoist only used to draw.
9..	11.0	19.0	35	4 28	0 55	1 05	63	Heavy	
10..	2.5	20.0	55	4 00	0 22	1 58	80	Heavy	
11..	3.0	19.0	55	8 30	0 15	1 51	70	Heavy	

The various parts of the experimental dredge were assembled and erected under the immediate supervision of Henry Flad, M. Am. Soc. C. E., in the fall of 1893. The tests were begun in November of that year and continued throughout the winter and the following spring. As a result of these tests the Allis-Reynolds pump at the bow of the boat was found to be deficient in engine power and the drag-suction at the stern of the boat could not be manipulated so as to give a regular and satisfactory supply of material. The Edwards pump gave good results and the jet agitator suction-head was found to be satisfactory. The jet pump required extensive alterations before the required results could be secured.

The buoyancy of the floating pipe line was too small and great care was required to prevent sinking the pipes by getting a trifle over 10% of sand in them.

Another unexpected difficulty developed in the use of these pipes. When swinging freely in the current with the lower end open and the pump running, the pipes would kink up at the joints. This was attributed to the reaction of the discharge against the water in which

the pipes were floating. After considerable experimenting with jets discharging in the air and in water, the conclusion was reached that the kinking was due to the centrifugal force of the flowing water acting at the flexible joints of the pipe. That is to say, when the pipe swings freely in the current it is never straight, and any bend met with by the water flowing in the pipes at a high velocity is naturally exaggerated. This difficulty was fully overcome by attaching a baffle plate to the last section, a short distance from the end of the pipe, to receive the impact of the discharge. By shifting this baffle plate so that the discharge will strike it at an angle, the pipe line can be deflected to the right or left.

The experiments had solved many of the difficulties, and attention was then turned to utilizing this dredge for practical work. The Allis-Reynolds pump and the drag suction were discarded. The Edwards pump was shifted and attached to the jet suction. In the spring of 1895 a cabin was built for the accommodation of the crew, and the first dredge for the elimination of obstructing sand bars on the lower Mississippi river was ready for actual work during the low-water season of 1895.

In the fall of 1894 the first attempt to aid navigation was made near Cape Girardeau, Mo., where there was a bar about 1 600 ft. long with from 3 to 4 ft. of water. Work began on October 19th, and by October 26th a channel 6 ft. deep had been made and this channel remained good throughout the season.

During the winter of 1894–5 a large number of tests were made to determine the capacity of the dredge. The immense amount of material constantly moving along the bottom of the river and the scouring effect of the current, made it impracticable to ascertain the amount moved, by measuring the material in place and then measuring the excavation. A measuring barge was therefore fitted up with suitable valves, to attach to the lower end of the discharge pipe where the discharge could be deflected into the barge for a known interval of time when the running conditions were about normal. This barge is 107½ ft. long., 24 ft. wide and 6¼ ft. deep. A special floor was laid in the bottom, and tight bulkheads were built near each end. The gunwales were stiffened with trusses in order to carry with safety the unusual load put in the barge. A 6-in. gate-valve was placed below the floor, next to the bottom planking at each corner of the loading

space, or spoil bin, of the barge. Pipes lead along the gunwales to each of the valve pipes, and are arranged so as to be connected with the pressure pumps of the pile sinkers. A well with removable sides is placed around each gate-valve so that when the barge is filled the water may be drawn from the top without disturbing the sand. There are two gauges placed on each side of the spoil bin and near the ends of the same. By means of simultaneous readings on these gauges the depth of material is determined. In making a test the barge is attached to the lower end of the pipe-line by means of a rubber pipe 6 ft. long and of the same diameter as the floating discharge pipe. This carries the discharge into the barge and to a point near the forward bulkhead of the spoil bin. Here a valve is provided that will deliver the discharge either into the river through an opening in the bottom of the barge or into the spoil bin, as may be desired. This valve (shown in Fig. 8) operates, both in opening and closing, by releasing heavy weights which cause the valve to revolve almost instantaneously.

Fig. 8 shows the opening to the spoil bin closed and the outlet through the bottom of the barge into the river, open. The brakes shown, hold the valve in any desired position. In setting the weights ready for a test, the weight *W*, which is shown at the bottom of the bin, is raised about 2 ft. above the button *O*, and supported by a rope attached to the framework above. It is also attached to the button *O* by a second rope. When ready to throw the valve down, so as to discharge into the spoil bin, the first rope is cut, which allows the weight *W* to drop about 2 ft., and the entire weight *W* is taken by the cable *K* which revolves the valve to its lower position, closing the outlet to the river and opening into the spoil bin. The brakes controlled by the lever *F* are put on to hold the valve in place, and the weight *W* is entirely released and drops to the bottom. The weight *A*, used for closing the valve to the spoil bin, is supported by the hook *N* some 2 ft. above the button *B* at the end of the cable *C* which passes through the weight, the opposite end passing around a pulley fixed to the valve shaft. When the spoil bin is full, the weight *A* is dropped from the hook *N* by raising the lever, and at the same instant the brakes are released and the valve moves back to its first position, throwing the discharge into the river. It is found necessary to start the valve with a jerk.

In making a test, the dredge pumps are started and the dredge is pulled ahead as in actual work, the barge-valve being set so as to discharge the spoil into the river. Sufficient water is let into the spoil bin through the gate-valves to cover the floor, and the gauges are read. This is done so as to be sure that none of the volume pumped in will go under the floor where it cannot be measured. When everything on the dredge is running smoothly and at about the normal rate, the dis-

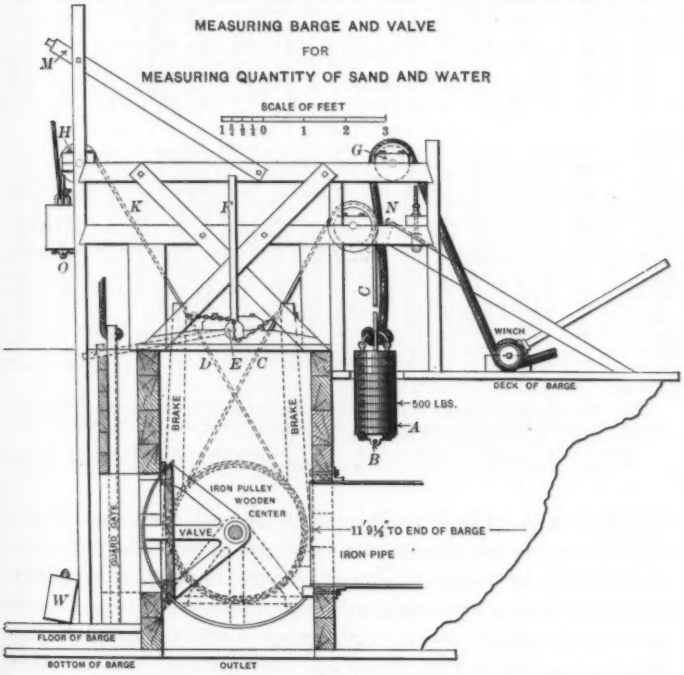


FIG. 8.

charge-valve into the spoil bin is thrown open and the timing hand of the stop-watch is started. In throwing the valve open to the spoil bin, the opening to the river is closed by the same valve. When all the material that the barge will safely hold has been discharged into the barge, the valve to the spoil bin is closed and opened to the river again. At the same instant the timing hand of the stop-watch is stopped. After a few minutes' time, necessary for the agitated water in

TABLE No. 2*a*.—Capacity and Efficiency Tests

Number of test.	Duration of test, in seconds.	Depth of Water at Bow.		Rate of movement ahead of dredge. Feet per second.	Edwards Pump.										Jet Pump, 6 Jets, 2½ ins. Diameter	
		Port.	Star.		Revolutions per minute.	Steam pressure.	I. H. P.			Head.					Delivery head. Feet of water.	Revolutions of jet pump.
										Suction head.		Mean delivery head. Feet of water.	Mean velocity head by barge measurement. Feet of water.	Total mean head. Feet of water.		
							H. P. Cyl.	L. P. Cyl.	Total.	Mean head. Ins. of mercury.	Mean head. Feet of water.					
7.....	150	6.5	7.3	.075	118	154	166	153	319	9.18	10.40	15.53	2.75	28.68	20.5	224
8.....	138	7.0	8.0	.071	118	153	165	154	319	9.32	10.56	15.80	1.90	28.26	20.3	224
9.....	122	5.5	6.5	.037	117	150	165	147	312	9.21	10.44	15.39	2.11	27.94	21.0	234
10.....	140	6.0	6.5	.045	116	143	154	137	291	8.65	9.80	15.38	2.11	27.29	20.8	230
11.....	155	6.5	7.3	.058	119	155	166	153	319	9.20	10.43	16.59	2.40	29.42	20.9	230
12.....	138	6.5	7.5	.037	118	150	164	155	319	8.98	10.18	15.23	2.23	27.64	20.1	228
13.....	123	8.2	8.3	.037	115	150	166	150	316	9.29	10.53	14.08	2.58	27.19	21.0	230
14.....	135	7.0	7.7	.037	118	150	163	151	314	8.90	10.09	15.90	2.02	28.01	19.8	226
15.....	131	8.2	8.0	.030	119	153	167	154	321	9.33	10.57	15.32	2.61	28.50	21.0	236
16.....	183	10.0	9.5	.037	123	146	159	147	306	7.11	8.06	22.13	1.48	31.67	20.5	228
17.....	194	5.5	5.0	.025	127	138	156	138	294	7.62	8.63	22.80	0.88	32.31	20.2	224
18.....	197	5.5	8.0	.030	130	140	159	140	299	6.42	7.27	22.64	0.96	30.87	20.8	230
19.....	174	5.0	5.0	.050	130	146	166	152	318	7.16	8.12	23.53	1.32	32.97	20.2	222
20.....	193	7.0	6.2	.021	125	130	145	129	274	6.44	7.30	25.52	1.24	34.06	19.8	216
21.....	184	3.5	4.0	.050	129	143	167	151	318	7.17	8.13	23.36	1.39	32.88	21.0	230
22.....	180	5.0	5.0	.050	120	140	155	145	300	7.68	8.70	20.73	1.80	31.23	20.0	226

The first nine tests were made with 604.5 ft. of pipe between the pump and the valve
Diameter of discharge pipe, 30 ins. Distance from suction head to pump, 101 ft.
The area of spoil bin in test barge, 2 544.01 sq. ft.
The average capacity of sand per hour with the short discharge pipe was 679 cu. yds.,
The sand pumped per hour per indicated horse-power with the short discharge was

the spoil bin to settle down, the gauges are read, the pumps on the pile sinkers are started, the gate-valves are opened and the water is forced out, leaving the sand to be measured later. This is done by measuring the depth on eleven cross-sections at eleven points on each section, all equally spaced. The average depth multiplied by the known area gives the volume of sand. The differences of the gauge readings before and after filling give the depth of material pumped in. This multiplied by the area gives the total volume of sand and water. From this, and the time required to pump such volume, the various functions of capacity per hour, velocity per second, efficiency, etc., are determined. The material enters the barge with such force that the sand is not distributed uniformly over the bottom, but piles up in ridges on one side or the other.

Sometimes the sand is measured in a box 1 ft. deep, 5 ft. wide,

OF UNITED STATES DREDGE *ALPHA*. 1894–95.

Measuring Barge.									Sand.		Efficiency.		
Mean depth of water in barge before test.	Mean depth of water in barge at end of test.	Mean depth of water pumped.	Cubic feet of material pumped.	Cubic feet per second.	Velocity per second. Feet.	Cubic feet of sand pumped.	Percentage of sand.	Capacity of pump, in cubic yards per hour.	Weight of 1 cu. ft., dry.	Percentage of voids.	Work done in foot-pounds per second as measured by barge.	Work done in foot-pounds per second as measured by indicator cards.	Percentage.
.626	4.478	3.852	9 799.52	65.33	13.31	552.0	5.63	491	106	35	117 106	175 450	66.75
.707	3.663	2.956	7 520.09	54.49	11.10	936.5	12.45	905	104	33½	96 244	175 450	54.85
.575	3.340	2.765	7 034.18	57.66	11.74	766.5	10.89	838	104	38	100 688	171 600	58.67
.438	3.610	3.172	8 069.60	57.64	11.74	614.0	7.61	585	108	36½	98 312	160 050	61.42
.406	4.120	3.714	9 448.45	60.96	12.41	970.0	10.27	835	104	37½	112 062	175 450	63.87
.505	3.713	3.208	8 161.18	59.14	12.04	520.0	6.37	508	109	36½	102 187	175 450	58.24
.398	3.450	3.052	7 764.31	63.12	12.85	715.0	9.21	775	109	33½	107 250	173 800	61.71
.473	3.465	2.992	7 611.67	56.38	11.48	660.0	8.67	652	106	36½	98 687	172 700	57.14
.448	3.720	3.272	8 324.00	63.54	12.94	516.3	6.20	526	106	38½	113 187	176 550	64.11
.562	4.018	3.456	8 792.09	48.04	9.78	460.0	5.23	335	100	41½	95 062	168 300	56.48
.438	3.260	2.822	7 179.19	37.01	7.53	530.0	7.38	364	108	38½	74 750	161 700	46.23
.461	3.448	2.987	7 598.95	38.57	7.85	925.0	12.17	626	106	36½	74 437	164 450	45.27
.557	3.647	3.090	7 860.99	45.18	9.20	716.0	9.11	549	108	37½	93 125	174 900	53.25
.530	3.857	3.327	8 463.92	43.85	8.94	586.6	6.93	405	111	34½	93 375	150 700	62.02
.616	3.975	3.359	8 545.32	46.44	9.46	663.0	7.75	446	107	40	95 438	174 900	54.57
.643	4.392	3.749	9 537.49	52.98	10.79	849.0	8.90	629	103	41½	103 438	165 000	62.69

in the test barge. The other seven tests were made with 1 059.5 ft. of pipe.
Diameter of suction pipe, 30 ins. The suction was lowered 12 ft. below the water surface.

and with the long pipe, 479 cu. yds.
2.16 cu. yds., and with the long line, 1.59 cu. yds.

and 10 ft. long. The floor of the barge is cleared off so as to give room for the box. The sand is then shoveled into it without packing, and the top is smoothed off with a straight edge. This method gives about 22% more volume than when the sand is measured in place, but as it necessitates handling the material twice, it has been abandoned.

The results of twenty-two tests of the dredge *Alpha*, with the Edwards pump, are given in Table No. 2*a*.*

A new pump, similar to that on the *Delta*, with a 66-in. runner, 33 ins. wide, was put in the *Alpha* in July, 1897. Barge tests with this pump were made in June, 1898, the results of which are shown in Table No. 2*b*.

The time spent in experimenting with the first dredge was by no means wasted. There were many difficult problems of construction

* Report of C. W. Sturtevant, in the report of Chief of Engineers, U. S. A., 1895, p. 3795.

TABLE No. 2*b*.—Capacity and Efficiency Tests

Number of test.	Duration of tests, in seconds.	* Conditions.			Main Engines.					Main Pump.				Jet Pump.	
		Length of discharge pipe from stern of dredge to valve in measuring barge, in feet.	Depth of suction, in feet.	Depth of water, in feet.	Forward movement of dredge, in feet, per minute.	Steam pressure.	Revolutions per minute.	I. H.-P.			Head.—Feet of Water.				Revolutions per minute.	Head.
								H. P. Cyl.	L. P. Cyl.	Total.	Suction.	Delivery.	Velocity.	Total.		Delivery, feet of water.
1..	69.5	525	12	....	....	160	156	217.3	250.0	467.3	9.6	25.8	3.1	38.5	....	.....
2..	95	525	12	6.9	6.9	165	152	217.3	236.0	453.3	13.6	30.4	3.0	47.0	235	20.7
3..	98.5	1 057	12	7.5	2.2	165	159	186.1	151.6	337.7	7.4	35.0	1.4	43.8	230	20.0
4..	101.5	1 057	12	5.7	2.9	125	148	170.6	187.0	357.6	10.2	35.0	1.2	46.4	228	19.8
5..	101.5	1 057	10	6.2	6.5	156	155	198.0	199.2	397.2	10.2	32.7	2.0	44.9	228	19.8
6..	102	1 057	12	....	....	155	155	207.5	217.3	424.8	7.4	24.6	2.4	34.4	....	.....
7..	101.5	1 057	12	5.6	5.4	160	157	183.1	178.7	361.8	10.2	53.4	0.8	64.4	228	19.7
8..	120	1 057	12	4.6	3.5	158	162	164.0	165.9	329.9	9.1	38.5	0.2	47.8	230	20.0
9..	109	1 057	10	5.3	6.3	155	152	196.2	194.4	390.6	9.1	28.1	1.5	38.7	233	20.5
10..	63	525	12	6.7	6.8	160	152	213.1	262.8	475.9	14.2	30.4	3.1	47.7	233	20.5

* Suction pipe, 30 ins. diameter; discharge pipe, 30 ins. diameter. Distance from

† Delivery head observed 12 minutes before test.

and manipulation solved, and the efficacy of dredging at all in a stream which moves vast quantities of material on its own account was tested to some extent. The results of all these experiments pointed clearly to dredging as the most promising method of temporarily improving low-water navigation that had so far been suggested or tried. The time had now come to provide a sufficient number of dredges to clear the obstructing reefs in so short a period of time that the interruption to navigation would be very slight. Dredging, however, had not yet been authorized specifically by Congress, and the amount of money available for the construction of dredges was rather limited.

With a view to covering the ground still more fully, and to get the benefit of the best dredging experience available, a circular was sent out in August, 1894, to engineers, contractors and builders of dredges, inviting "Informal plans and suggestions as to the methods and machinery best adapted to the work." The capacity of the required dredge was to be 1 600 cu. yds. of sand per hour. Several replies were received, and three firms were requested to prepare

OF NEW PUMPS ON THE DREDGE *ALPHA*, JUNE, 1898.

Measuring Barge. Area of water = 2 558.7 sq. ft. Area of sand = 2 532.5 sq. ft.								Efficiency. Foot pounds of work done per second.			Sand pumped per hour, in cubic yards, per I. H. P.	Kind of material.	Remarks.
Mean depth of material pumped, in feet.	Quantity of material pumped, in cubic feet.	Quantity of material, in cubic feet, per second.	Velocity of discharge, in feet, per second.	Mean depth of sand, in feet.	Quantity of sand, in cubic feet.	Percentage of sand.	Sand pumped per hour, in cubic yards.	Measured by material pumped into measuring barge.	Measured by indicator cards.	Efficiency per centum.			
1.90	4 861.53	69.95	14.2	.....	.....	.....	.....	168 317	257 015	65	.....	.....	Water test.
2.58	6 473.51	68.14	13.9	0.454	1 149.8	18	1 614	200 161	249 315	80	3.56	Med.	
1.73	4 426.55	47.34	9.6	0.244	617.9	14	881	129 593	185 735	70	2.61	fine sd.	
1.68	4 298.62	42.35	8.6	0.0731	185.1	4	243	122 815	196 680	62	0.68	Fine sand	
2.23	5 705.90	56.22	11.4	0.2632	666.5	12	876	157 767	218 460	72	2.21	Med. fine sd.	
2.42	6 192.05	60.71	12.4	.....	.....	.....	.....	130 526	233 640	56	.....	.....	Water test.
1.42	3 633.35	35.80	7.2	0.3531	894.2	25	1 175	144 095	198 990	72	3.25	Med.	
0.90	2 302.83	19.19	3.9	0.1883	476.9	21	530	57 330	192 445	30	1.61	fine sd.	
2.08	5 194.16	47.65	9.7	0.2931	742.3	14	908	†115 253	214 831	†54	2.32		
1.70	4 349.78	69.04	14.1	0.2800	709.1	16	1 501	205 825	261 745	79	3.15	.....	

pump to end of suction, 66 ft.; from pump to stern of dredge, 74 ft.

detailed drawings and specifications of the plant they proposed to furnish. These were submitted in December, 1894, and a contract was let to the American Hydraulic Dredging Co. of Chicago, Ill., for the construction of the dredge *Beta*, at a cost of $172 775. The contract provided that if the dredge fell short of the required capacity, the deduction from the price should be proportional to this difference; and if the capacity exceeded 1 600 cu. yds. per hour, then the price should be increased proportional to this excess up to 50 per cent. The dredge was completed and ready for testing in January, 1896.

DREDGE *BETA*.

This dredge has two independent dredging machines complete from suction to end of discharge pipes. The sand pumps are of the centrifugal pattern with runners 7 ft. in diameter and with 8 arms in each runner. The suction for each pump is 33¾ ins. in diameter, and is split near the pump so that the water enters the casing from both sides. The discharge for each pump is from a single 33-in. pipe leaving the pump chamber from the top. The suction for each pump divides near the forward end of the hull into three suctions, each 19½

ins. in diameter. A cast-iron elbow is riveted to the hull at the bow for each of the three branches, which are provided with elbows of hammered copper $\frac{3}{8}$ in. thick, and these work in the iron elbows and form a radial, telescopic joint. The axis of rotation is the center of a 7-in. shaft supported on brackets at the bow of the boat. The elbows are concentric with this shaft. These three suctions are framed together and can be raised or lowered, as one piece, through a depth of 20 ft.

Each of these suctions is provided with a vertical revolving cutter, 5 ft. in diameter and 5 ft. long, with 12 nickel-steel blades on each cutter. These serve to loosen up the material so that it will readily enter the suction. They are spaced 6 ft. apart from center to center. There are six of these revolving cutters for the two pumps. They are driven, through a system of spur gearing, by a cross-compound, non-condensing engine with $14\frac{1}{2}$ and 29-in. cylinders and an 18-in. stroke. The engines make about eight revolutions to one revolution of the cutters. The cylinders are some 20 ft. apart and are connected by a 5-in. pipe.

To support a portion of the weight of the cutter machinery, a pontoon is provided for each set of suctions. This pontoon is made of steel plates, and is built around the various pipes and frames. Each pontoon has a displacement of 1 000 cu. ft.

The sand pump shaft is of forged steel, 10 ins. in diameter, and 12 ins. in diameter where it passes through the pump runner. Stuffing-boxes are provided where the shaft passes through the pump casing. Each pump is operated by a direct-connected, triple-expansion, vertical, inverted, four-cylinder, tandem engine provided with jet condensers. The cylinders are $20\frac{1}{2}$, 33, 38 and 38 ins. in diameter, respectively, and the stroke is 24 ins. with the cranks set at 180 degrees. These engines are run at a speed of about 130 revolutions per minute, the indicated horse-power of each being about 1 250, with boiler pressure of 175 lbs. Each engine is provided with a Worthington duplex air pump and jet condenser, with cylinders 14 and 19 ins. and 15-in. stroke. They are also arranged to exhaust without condensing. The steam is supplied by four Heine boilers so arranged that they can be used together or independently, as may be desired. Each boiler has two shells 36 ins. in diameter and $18\frac{1}{2}$ ft. long. The water legs are connected by 171 tubes, $3\frac{1}{2}$ ins. in diameter and $15\frac{3}{4}$ ft. long. There is one smokestack to each pair of boilers, each stack

being 64 ins. in diameter and 57 ft. high above the breeching, or 73 ft. above the water-line. The main steam pipe between the boilers and engines is 12 ins. in diameter. The usual steam gauges, blow-off valves, etc., are provided.

The water supply for the boilers and journal bearings is filtered by means of two filters, each 11 ft. long and 6 ft. in diameter. The filter bed is supported on a perforated cast-iron bed fixed near the bottom of each filter. There are three layers of brass wire-cloth with 10, 60 and 10 meshes per inch, respectively. These support a bed of crushed quartz made up of layers of different degrees of fineness and about 2 ft. thick. The sediment which gathers on the filter bed is stirred up by two sets of arms which can be revolved by means of gearing, and the clear water from one filter is used to wash the other. The filters are supplied by a duplex pump with 8-in. suction and 7-in. discharge, and the water is carried through an alum coagulant to the tops of the filters under a pressure of about 60 lbs. The filtered water is drawn from the bottom of the filters by the boiler feed-pumps, and passes through a vertical pressure heater provided with one hundred 2-in. corrugated copper tubes 73¾ ins. long. The exhaust steam from the cutter, the winding engines and the pumps passes through this heater.

The winding engines are placed near the bow of the boat. There are six drums operated by a double-cylinder, link-motion, reversing engine with 12½-in. cylinders and 15-in. stroke. Four of the drums are 24 ins. in diameter and 40 ins. long. Two of these drums are used for side warping, and are geared 25 to 1. The other two are used for pulling the dredge ahead, and are geared 30 to 1; 1 200 ft. of ⅞-in. wire rope is used for this purpose. The two end drums are 30 ins. in diameter and 28 ins. long. They are used for raising and lowering the suctions.

At the stern of the boat is a steam capstan and a spud hoist. There are two vertical anchor-spuds and one push-spud at the stern of the boat. The anchor-spuds are of oak, 24 ins. square and 40 ft. long. These were intended mainly as pivots on which to swing the boat, so that a wide cut could be made by moving the suction on the arc of a circle. This method is not well adapted to streams with a strong current. These spuds and the push-spud are raised or lowered by means of a 3-drum friction hoist moved by a double 8 x 10-

in. engine. The push-spud is an iron beam 28 ft. long, with a steel shoe at the lower end. It can be raised up into a recess in the hull when not in use. The inner end of the beam is attached to the piston rod of a hydraulic cylinder 7 ft. long and 15 ins. in diameter. The piston rod passes through the hull plating in a stuffing-box. This spud has never been used.

The machinery is mounted on a steel hull 172 ft. long and 40 ft. wide. It is 7 ft. 2 ins. deep in the waist, and for 36 ft. from the forward end and 16 ft. from the after end it is 10 ft. 10 ins. deep. These deep portions are decked over, as are also the guards, for the entire length. The plating on the sides of the hull is $\frac{3}{8}$ in. thick; the other plating outside is $\frac{5}{16}$ in. thick. The bow is double-plated on the head and rake. The cross floors, spaced 2 ft. between centers, are 12-in. I-beams, weighing 32 lbs. to the foot. On these, at intervals of $3\frac{1}{2}$ ft., are longitudinal stringers of the same form and height, weighing 40 lbs. to the foot. These floor frames are decked over with $\frac{1}{4}$-in. plating and extend to within 6 ft. of the bow. The space between this plating and the bottom is divided into ten water-tight compartments. The hull is further divided into seven water-tight compartments above the water bottom by means of five cross bulkheads and one short longitudinal bulkhead.

The bases of the pumps, engines and the boilers are set on the water bottom. Two coal bunkers are provided, with a capacity of about 30 tons each. The dredge is fitted with a traveling crane of ample capacity to handle all parts of the machinery.

No quarters are provided for the crew of this dredge. The cabin is only sufficient to protect the machinery. The boat is equipped with an electric light plant and a full complement of shop tools, such as lathe, drill press, etc.

The requirements of the contract fixed the limit of draft at $4\frac{1}{2}$ ft., and the width at 40 ft. When the dredge was completed, the draft was found to be about $6\frac{1}{2}$ ft.

The weights of the various parts are about as follows: Hull, 633 340 lbs.; main engines and pumps, 183 576 lbs.; boilers, 405 880 lbs.; cutter engine, 27 460 lbs.; forward hoist, 51 500 lbs.; spud hoist, 20 450 lbs.; ladders, 56 800 lbs. The total displacement when running, with suction and discharge pipes, boilers, filters, heaters, etc., full of water, and a supply of coal on board, is about 1 175 tons.

U.S. Dredge "GAMMA"
View of Hull looking forward
Sept 15 1896

FIG 1.

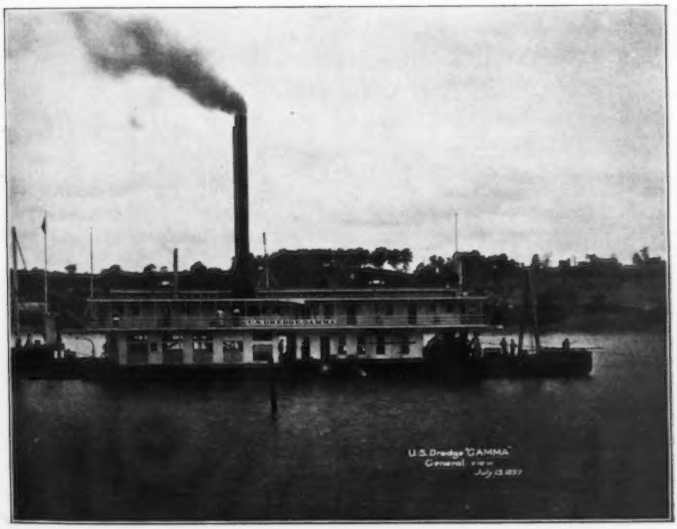

U.S. Dredge "GAMMA"
General view
July 13 1897

FIG. 2.

The discharge consists of two independent pipe lines, each 1 000 ft. long. A deflecting baffle plate is provided for the end of each line. Eight of the sections of each line are 100 ft. long, and four sections are 50 ft. long. When the pipes are empty, the pontoons draw about 14 ins. of water. The pontoons are made of $\frac{3}{16}$-in. tank steel, and are fitted with water-tight bulkheads about 16 ft. apart. In section they are the shape of a semi-cylinder, with an outer radius of $30\frac{3}{4}$ ins., and an inner radius of $16\frac{3}{4}$ ins. The discharge pipe lies in the float thus formed, and is made of $\frac{1}{4}$-in. steel. The different lengths are coupled about as described in connection with the *Alpha*.

Quite a number of defects were developed in the use of this dredge, many of which were remedied. At first the cutters all worked in the same direction, and the result was that the dredge was pulled sidewise out of the cut. This was remedied by changing one set of cutters to work in the opposite direction. The breaks in the gearing of the cutter machinery were frequent, although the spur gears were made of nickel steel, and the pinions of phosphor bronze. The 6-drum hoist also gave considerable trouble. The cutters were found to be very much longer than necessary, and their operation drew heavily on the boiler capacity. The unexpected draft developed difficulties in coaling, and in maneuvering the dredge over the shoal bars.

The preliminary tests of the dredging machinery began about the middle of January, 1896, and continued until March 1st. Of the four hundred working hours embraced in this period, two hundred and fifty-five hours were used in repairs and changes and seventy-four hours in actual pumping. The capacity tests were begun on March 10th, and continued for about a month. There were ten tests made in ordinary river sand, one gravel test and one water test. The tests were made in the test barge described in the preceding pages. Two valves were provided, so that both pipe lines discharged into the barge at the same time, if desired.

In the gravel test the face of the bank dredged was about 7 ft. high, and only about 1 ft. of it was gravel. In this test one valve was first opened and the barge filled. The water was then syphoned out, and the other valve was opened and the barge again filled. The gauge readings and time of each were, of course, noted. Tests 9 and 10 were made with only one valve open, the other pipe line discharging in the river.

TABLE No. 3.—Capacity and Efficiency

Number of test.	Duration of tests.	Depth of water.	Depth of suction.	Forward movement per minute.	Pumps' Revolutions per minute.		Average boiler pressure.	I. H.-P.			Suction head. In feet of water.		Delivery head. In feet of water.		Difference between elevation of gauges.	Velocity head.	Total head.	
					Starboard.	Port.		Starboard engine.	Port engine.	Total.	Starboard pump.	Port pump.	Starboard pump.	Port pump.			Starboard pump.	Port pump.
	Secs.	Ft.	Ft.	Ft.											Ft.			
1	35	8.3	14.6	7.5	150	149	177	1 280	.....	2 561	19.3	19.8	22.7	25.2	+8.4	6.4	57.1	60.
2	68 5/6	11.5	18.5	3.1	140	157	169	.....	1 296	2 593	15.9	18.2	30.6	34.5	.....	2.3	57.1	63.3
3	37 13/100	10.0	18.5	2.6	161	157	161	1 293	.....	2 586	14.7	14.7	36.3	39.7	.....	2.1	61.5	62.9
4	64 7/8	9.8	18.3	3.6	151	148	178	.....	1 223	2 447	14.7	17.0	35.1	26.1	.....	2.9	61.1	54.4
5	26 1/2	9.2	17.5	5.0	153	154	176	1 196	.....	2 392	20.4	18.7	29.4	37.4	.....	2.8	61.0	67.3
6	55 3/4	9.5	17.6	4.0	144	151	173	.....	1 300	2 609	18.7	18.1	25.5	32.8	.....	3.0	55.6	62.3
7	53 43/100	9.5	17.5	7.5	146	148	172	1 105	.....	2 211	17.0	19.0	31.7	27.6	.....	3.3	60.4	58.0
8	50 1/2	10.1	18.4	10.0	147	148	174	.....	1 247	2 495	20.0	21.5	28.3	29.2	.....	2.8	59.9	61.9
9	102 3/4	9.5	18.7	8.6	141	143	176	1 170	.....	2 340	19.3	21.0	23.8	24.9	.....	2.5	54.5	57.3
10	95 1/10	9.5	18.8	8.2	142	144	174	.....	1 199	2 398	19.3	20.4	24.9	24.7	.....	3.7	56.3	57.2
	119	.....	.....	.....	149	152	170	1 187	.....	2 374	18.1	18.9	21.5	21.5	.....	4.0	52.1	52.8
	78 1/10	4.5	11.5	3.7	146	157	163	.....	1 161	2 322	17.6	13.6	22.7	35.0	.....	3.2	51.9	60.2
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Length of port suction from intake of pump = 85.9 ft. Length of port discharge pipe
Length of starboard suction from intake of pump = 100.3 ft. Length of starboard
Diameter of main suction = 33¾ ins. Diameter of discharge pipes = 33 ins. Area of
Revolutions of cutters per minute = 19. Average capacity of dredge in cubic yards

In all the tests the dredge was run for a considerable time in all respects as if doing actual dredging work, and the valves were opened at such times as the pumps were seen to be working under about normal conditions. In the mean time steam gauges were read, revolutions of pumps, cutter engines and winding drums were counted, and indicator cards were taken at intervals of about 5 minutes.

The results of these tests are shown in Table No. 3.*

The general conditions as to length of time required for efficiency tests and number of capacity tests were the same as described in connection with the *Gamma*.

The tests show an average capacity of 4 920 cu. yds. per hour, and, therefore, according to the terms of the contract, a bonus of $86 387.50 was earned by the contractor.

* Report of Assistant Engineer Wm. Gerig, in report of Chief of Engineers, U. S. A., for 1896, page 3643.

TESTS OF UNITED STATES DREDGE *BETA*.

Number of test.	Measuring Barge. Mean velocity. Feet per second.	Total material pumped per minute.	Amount of sand pumped per minute.	Percentage of sand.	Quantity of sand pumped per hour.	Depth of material pumped into barge.	Percentage of voids in wet sand.	Weight per cubic foot of dry sand.	Horse power developed as measured by material in barge.	Efficiency per centum.	Sand pumped per hour per indicated horse-power.	Remarks.
	Ft.	Cu. ft.	Cu. ft.		Cu. yds.	Ft.		Lbs.			Cu. yds.	
1	20.8	14 812	391	2.6	868	3.41	35.2	96.9	1 685	65.8	0.29	
2	11.9	8 479	1 281	15.1	2 847	3.82	32.6	98.1	1 098	42.3	1.10	
3	11.6	8 268	2 859	34.6	6 354	2.03	34.2	97.5	1 298	50.3	2.46	
4	13.8	9 809	2 245	22.8	4 988	4.18	33.7	98.8	1 298	53.0	2.04	
5	13.5	9 608	3 509	36.4	7 798	1.65	34.8	98.1	1 558	65.2	3.26	
6	14.0	9 956	2 183	21.9	4 850	3.77	35.1	97.8	1 335	51.2	1.86	Pumping sand and water.
7	14.0	10 000	1 743	17.4	3 872	3.54	32.5	99.4	1 300	58.8	1.75	
8	13.5	9 635	2 798	29.0	6 217	3.20	33.3	97.5	1 399	56.1	2.49	
9	13.9	9 870	2 847	28.9	6 327	3.33	34.6	97.5	1 318	55.3	2.70	One valve open.
10	14.9	10 639	2 287	21.5	5 082	3.35	34.8	97.5	1 367	57.0	2.12	One valve open.
	16.5	11 430	.....	....	.....	4.51	....	.....	1 134	47.7	....	Water test.
	14.4	10 505	499	4.7	.....	1.83	....	.....	1 165	50.2	0.48	Gravel test.
	14.1	10 107	2 214	23.0	4 920	3.22	....	.....	1 365	55.5	2.00	Averages of first ten tests.

from pump to valve in measuring barge = 1 161.7 ft.
discharge pipe from pump to valve in measuring barge = 1 147.7 ft.
measuring barge = 2 535.3 sq. ft.
per hour by box measurements = 4 920, or about 4 330 cu. yds. measured in place.

After completing the required tests, sundry repairs and alterations were made, to put the dredge in condition for actual work.

During the low-water seasons of 1896 and 1897 the enormous capacity of the *Beta* was fully demonstrated. An account of the character and cost of this work will be given later.

Before the dredge is again put into service for the low-water season of 1898, numerous changes will be made. The hull will be widened to 58 ft. and lengthened, so as to reduce the draft to 4½ ft. About $41 000 has been retained from the contract price to do this work, as the specifications required that the draft should not exceed 4½ ft. A cabin for the accommodation of the crew will be erected; the 6-drum hoist will be replaced by four detached single-drum hoists; the cutter engines, cutters and other parts belonging to the present suction will be replaced by a jet suction and pumps. This is done because it has been

found in actual practice that mechanical agitators are unnecessary in the sands of the Mississippi River. The wear and tear of the cutter machinery is a very large item of expense, to say nothing of the power required. The jet agitators are quite efficient, are much more economical in point of repairs and power required, and are more simple in manipulation. The push-spud and one anchor-spud will be discarded. The other anchor-spud will be moved to the bow of the boat. The spud-hoist will be discarded. The forward battery of boilers will be turned end for end in order to properly distribute the weights under the new arrangements, and to improve the facilities for coaling. Much of this work would probably be deferred were it not that the boat must be put into dry dock to make the hull repairs, and this opportunity is seized for making the changes outlined.

A general view of the *Beta*, as she will appear after remodeling, is shown in Fig. 9.

Dredge *Gamma*.

The Act of Congress of June 3d, 1896, was the first to formally recognize and require the use of dredge boats and other devices as an adjunct to the permanent improvement of the lower Mississippi River. The Act referred to requires that as much of the money appropriated as may be necessary:

"Shall be expended in the construction of suitable dredge boats and other devices and appliances, and in the maintenance and operation of the same, with a view to ultimately obtaining and maintaining a navigable channel from Cairo down, not less than 250 ft. in width and 9 ft. in depth, at all periods of the year, except when navigation is closed by ice."

This formal recognition of the necessity of temporary relief for low-water navigation resulted in the early construction of four more dredges.

The contract for the *Gamma* was let in July, 1896, to the Bucyrus Steam Shovel and Dredge Co., at South Milwaukee, Wis. The capacity required was 800 cu. yds. of ordinary river sand per hour, delivered through 1 000 ft. of pipe with a single centrifugal pump. The price paid was $85 530.60, and the time fixed for completion was nine months. This dredge was used in actual work throughout the low-water season of 1897, and was found to be very satisfactory, both in capacity and economy.

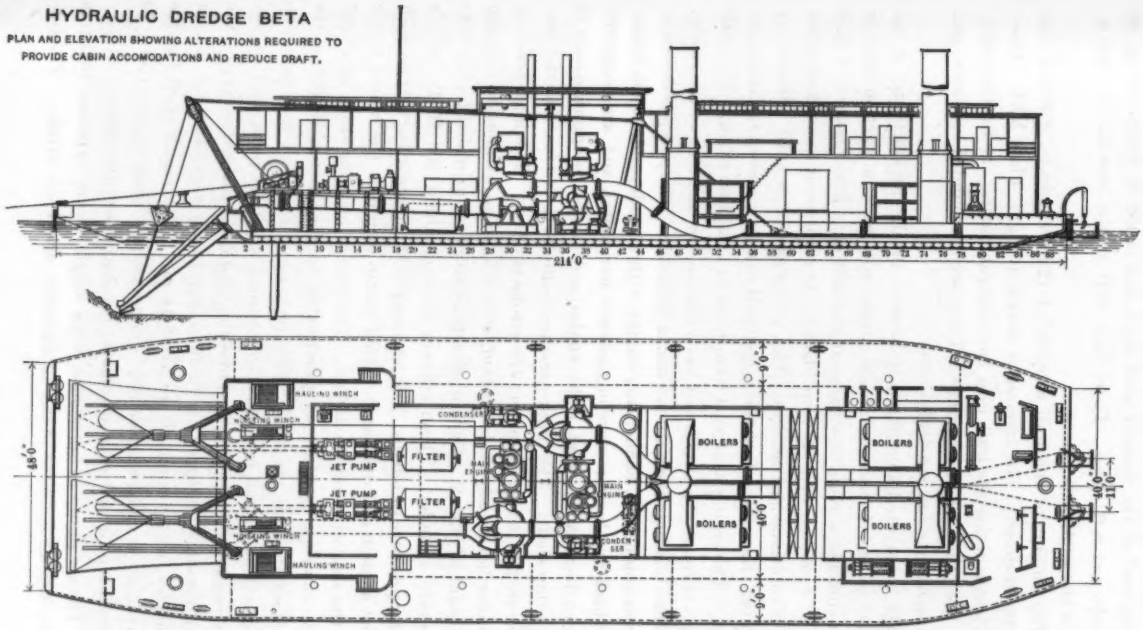

HYDRAULIC DREDGE BETA
PLAN AND ELEVATION SHOWING ALTERATIONS REQUIRED TO PROVIDE CABIN ACCOMODATIONS AND REDUCE DRAFT.
211'0"
85'0"
HAULING WINCH
CONDENSER
JET PUMP
FILTER
MAIN ENGINE
BOILERS
40'0"
11'0"

FIG. 9.

The hull of the *Gamma* is of steel, and is 138 ft. long over all, 38 ft. wide and 8 ft. deep. There is a well at the bow 32½ ft. long, in which the suction is placed.

The framing of the hull consists of 12-in. channels, stiffened with I-beam keelsons. The framing is shown in Fig. 1, Plate XXV. Cross bulkheads divide the hull into two compartments, one for the boiler, and the other for the engines. These are surrounded by water-tight compartments and are decked over.

The main dredging pump is located in the forward part of the engine room. It is a centrifugal pump, with a 24-in. suction inlet on each side and a 34-in. discharge at the bottom. The runner is 5 ft. 9 ins. in diameter, and has four blades. It revolves at a speed of about 150 revolutions per minute. The pump casing is split horizontally through the axis, so that the upper half can be removed in making repairs. The casing is of cast iron, from 1¾ to 2½ ins. thick. The shaft passes through the pump, and has a bearing on each side of the casing. At these bearings the shaft is 8 ins. in diameter. The pump is driven by a cross-compound, condensing engine with an independent condenser. The high and low-pressure engines are horizontal, and are connected to two disc cranks set at right angles and keyed to opposite ends of the pump shaft. The high-pressure cylinder is 18 ins. and the low-pressure 32½ ins. in diameter; the stroke is 22 ins. The high-pressure cylinder has an adjustable cut-off, with a hand adjustment to regulate the point of cut-off. Expansion relief-valves are provided for the low-pressure cylinder. These engines develop about 500 H.-P., with a boiler pressure of 140 lbs. The jet pump is of the centrifugal type, with 18-in. suction and discharge. This pump supplies the water to stir up the sand at the suction head. The runner has four arms, with steel tips, running as close as practicable to the casing, to obtain the greatest available pressure. This pump and its engine rest on a common bed plate, and have a flange-coupled shaft for pump and engine. The engine is a compound condensing engine of the marine type. The high-pressure cylinder is 12 ins. and the low-pressure 22 ins. in diameter, with a common stroke of 14 ins. The crank shaft has the cranks set at right angles. The cylinders have plain slide valves. All parts are provided with automatic apparatus for lubrication.

The air pump is horizontal, with single steam cylinder 10 ins. in diameter, air cylinder 18 ins. in diameter, and 18-in. stroke. The con-

U.S. Dredge DELTA
Main Dredge Pump and Pump Runner
March 3, 1937

FIG. 1.

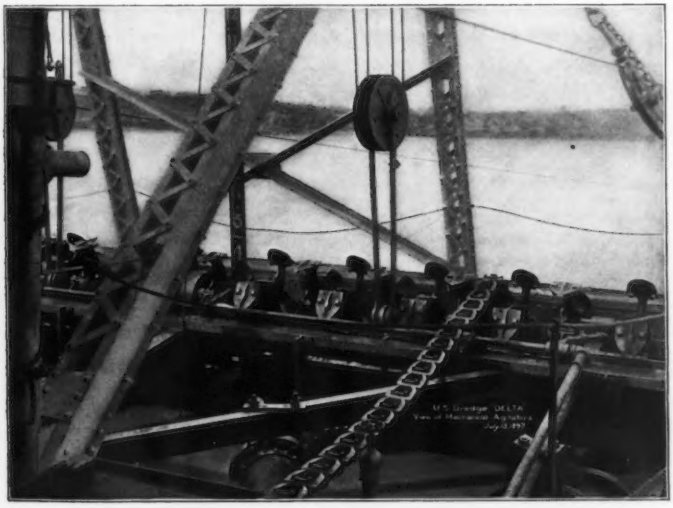

U.S. Dredge DELTA

FIG. 2.

denser receives the steam from both main and jet pumps, and is so arranged that the steam can pass directly to the atmosphere. The overflow from the condenser passes through a chamber, forming a hot-well for the boiler feed pumps. There are two feed pumps and one fire pump, so arranged that any one of them can be connected with the feed-water pipe or the fire hose. These pumps are vertical, duplex, outside-packed plunger pumps, with 7½-in. steam cylinders, 4½-in. water plungers and 8-in. stroke. An ordinary sand filter, with alum as a coagulent, is provided to filter the water used in the galley and cabin. A separate pump forces the water through the filter to a tank on the roof, and from there it is piped to various parts of the boat.

The main hauling winches are located on opposite sides of the boat near the bow. They are driven independently and are provided with fast and slow feed controlled by clutches. The drums are 42 ins. in diameter and 42 ins. long, which gives space for 1 200 ft. of ¾-in. wire rope. Each drum is driven by a pair of 7 x 7-in. double-cylinder engines with cam reverse, and the power is transmitted through a combination of worm and spur gearing. The movement is controlled by means of a brakewheel and strap. The speed ratio is 81 to 1 for fast and 493 to 1 for slow speeds. The hoisting engine for raising the suction pipe has a drum 24 ins. in diameter and 24 ins. long. It is fitted with brake, spur gear, pinion, clutch and shifting device. This engine also operates a shaft terminating in gipsy heads, which can be used in lieu of the capstans. The whole is driven by a pair of horizontal, double-cylinder, 8 x 10-in., plain, slide-valve engines, provided with steam reverse.

The anchor spud is hoisted by means of an upright, single-acting, steam cylinder, 18 ins. in diameter and 6-ft. stroke. The piston is attached to a cam clamp at its upper end, which grips and holds the spud against the slides. Steam enters at the bottom of the cylinder through a three-way valve, raising the piston and spud to the height of its movement. When the valve is turned to the exhaust port the piston and clamp descend, the spud being supported by a rack and pinion. The pawl locking the pinion is hinged between its center of movement and point, and the tripping is effected by making the pawl buckle on itself so that the point turns under. This releases its hold and allows the spud to drop.

Steam for the above-described plant is furnished by six boilers 48 ins. in diameter and 28 ft. long, with five 11-in. flues in each. These

boilers are arranged in two batteries so that they can be used separately if desired. They are designed to carry a pressure of 140 lbs. The fire-bed and ash-pan rest directly on the keelsons. Directly in front of the fire doors are coal bunkers having a capacity of 40 tons. The bottoms of the mud drums are below the water-line, hence a special cleaning device is provided by means of a tank set between the keelsons under the mud valves. The mud and water remaining in the drums are drawn off into the tank, and then syphoned out. The feed water is heated by passing through two pipes hung in brackets from the sides of the parting wall between the two battery furnaces.

The two intake pipes at the pump casing run forward to the suction head. They are hinged to the boat at the bow by two flanges connected by a pivot pin on the lower side and provided with a circular stuffing-box, making a radial joint that will allow the suction to be lowered to a depth of 15 ft. Outside of the joint the pipes and suction head are framed together and rigidly connected so as to form essentially one piece. At the suction head the pipes are 11 ft. apart from center to center. The suction head for each pipe is 8 ft. long and they are 3 ft. apart, forming one suction head 19 ft. long over all. The suction head proper has two inlets, one for the upper and one for the bottom intake, and between the two is a triangular pressure chamber running the whole length of the head. This connects directly with the jet pump. This chamber has nine 2½-in. nozzles through which the water from the jet pump is forced with sufficient pressure to loosen the sand in front of the suction. The discharge pipe is 34 ins. in diameter. It runs from the bottom of the pump casing along the floors between the two central keelsons, under the partition walls between the batteries of boilers, and through the stern of the hull, with the center of the pipe 4 ft. above the bottom of the hull at its exit. Near the pump the entire pipe is below the water-line, and the priming is done by means of a steam syphon at the top of the pump casing. The floating discharge pipe is 1 000 ft. long, divided into 20 sections, each 50 ft. long. They are made of ¼-in. tank steel. The pipes are floated by means of 40 cylindrical pontoons, each 23 ft. 9 in. long and 30 ins. in diameter. These are made of $\frac{3}{16}$-in. tank steel. They are attached to the discharge pipe by means of truss frames constructed of bar and angle irons, so designed as to receive and clamp the discharge pipe and carry the pontoons on either side. The pipe line is

PLATE XXVII.
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attached to the hull section of the discharge pipe by means of a male and female bevel-flanged coupling, a davit being used to swing the floating pipe into position.

The hull has a cabin 97 ft. long and 29 ft. wide, which protects the machinery and provides quarters for the crew. There is also a repair shop, provided with a lathe, drill press, emery grinder and other appliances needed in making ordinary repairs. An electric plant furnishes light for one 4 000-candle-power search-light, four arc-lights of 1 200-candle-power each, and 75 incandescent lamps of 16-candle-power each.

All the winches, the spud hoist and the search-light are manipulated from the operating room. This dredge is towed from point to point, and while dredging is operated similarly to the *Alpha*.

Four 10-in. and four 12-in. hydraulic piles 33 ft. long are provided, similar to that shown in Fig. 7. A general elevation of this dredge is shown in Fig. 2, Plate XXV, and the arrangement of the machinery, etc., may be seen in Fig. 10.

This dredge was tested near St. Louis, Mo., in August, 1897, and, after the completion of the tests, she was used in actual dredging between Cairo and Memphis until early in December of the same year. The general efficiency test, called for by the contract, required that the dredge should be operated 60 working days of 12 hours each in water from 5 to 15 ft. deep, and with sand of such different degrees of coarseness as will be found on the low-water bars. After this had been done and the machinery found satisfactory, then 20 capacity tests were required to be made with the suction at different depths. This last requirement was considered filled when the total amount pumped per hour divided by 20 was equal to or exceeded the required capacity of 800 cu. yds. per hour.

The weights of the principal parts are as follows: Hull, 328 328 lbs.; cabin, 117 449 lbs.; main pump and engines, 74 722 lbs.; jet pump and engines, 21 717 lbs.; auxiliary engines, drums, levers, etc., 46 937 lbs.; air, feed and fire pumps, 15 695 lbs.; electric light plant, 7 700 lbs.; boilers and accessories, 325 911 lbs.; suction head, 49 534 lbs.; floating discharge pipe and pontoons, 244 916 lbs.; hull fittings, 31 580 lbs. Total, 1 019 623 lbs. The working draft of the dredge is about 46 ins.

Construction was begun in June, 1896, and the dredge was practically completed in March, 1897.

The results of the official tests are given in Table No. 4.

TABLE No. 4.—Capacity and Efficiency Tests of United States Dredge *Gamma*.

Number of test.	Duration of test.	Conditions.[1]		Forward movement of dredge per minute.	Main Engine and Pump.										Jet Engine and Pump. (Nine jets, 2¼ ins. diameter.)					
		Depth of water.	Depth of suction.		Steam pressure, pounds per square inch.	Vacuum in condenser, inches of mercury.	Revolutions per minute.	I. H.-P.			Head.				Revolutions per minute.	I. H.-P.			Head.	
								High-pressure cylinder.	Low-pressure cylinder.	Total.	Suction, feet of water.	Discharge, feet of water.	Velocity, feet of water.	Total, feet of water.		High-pressure cylinder.	Low-pressure cylinder.	Total.	Suction, feet of water.	Discharge, feet of water.
	Seconds.	Feet.	Feet.	Feet.																
1...	80.4	5.2	14.0	2.0	143	25.5	162	239.8	265.6	505.4	10.3	29.3	2.1	41.7	148	60.4	26.8	87.2	3.7	31.6
2...	90.8	7.0	14.0	3.9	135	25.0	176	212.7	266.6	479.3	8.0	35.0	1.8	44.8	146	56.6	26.0	82.6	4.0	31.6
3...	105.3	4.7	12.0	2.2	152	25.5	174	229.7	256.5	486.2	8.0	38.5	1.1	47.6	143	54.1	23.5	77.6	3.7	31.1
4...	81.2	4.0	11.0	1.8	162	25.0	163	215.6	221.3	436.9	7.5	30.9	2.0	40.4	144	55.3	24.5	79.8	3.7	30.6
5...	59.5	5.2	12.0	4·5	144	25.5	172	242.2	270.0	512.2	9.4	35.0	1.7	46.1	146	55.6	26.4	82.0	3.7	31.3
6...	40.6	4.3	12.0	5.2	139	26.0	165	228.6	249.0	477.6	9.6	38.7	1.5	49.8	144	53.0	24.2	77.2	3.8	33.4
7...	64.7	4.3	12.0	3.5	145	26.5	166	.....	.....	.....	9.2	41.5	1.0	51.7	142	49.4	22.4	71.8	3.8	31.3
8...	67.2	4.8	11.0	5.6	130	26.0	170	225.3	257.3	482.6	8.6	41.5	1.4	51.5	158	63.7	31.0	94.7	4.0	31.6
9...	69.7	5.8	15.0	2.3	140	24.0	166	240.0	240.6	480.6	8.0	33.9	1.8	43.7	160	66.1	32.7	98.8	5.2	34.0
10...	97.6	5.2	15.0	3.2	148	25.0	167	.....	.....	.....	14.3	45.4	0.4	60.1	165	74.1	38.3	112.4	4.2	36.8
11...	64.4	5.2	11.0	6.6	125	26.7	169	225.4	282.1	507.5	10.3	37.3	1.8	49.4	160	68.1	34.7	102.8	4.2	38.2
	74.67	5.06	12.6	3.71	141.6	25.52	168.2	228.81	256.56	485.37	9.38	37.00	1.51	47.89	150.5	59.67	28.23	87.90	4.00	32.86
SPECIAL TEST.																				
12...	63.8	6.3	11.0	2.2	142	24.0	170	239.0	265.2	504.2	8.6	30.4	2.6	41.6	.....	.....	.....	.....	.....	.....

TABLE No. 4—(*Continued*).

Number of test.	Measuring Barge (Area of water = 2 538.7 sq. ft.; area of sand = 2 532.5 sq. ft.)										Efficiency.					
	Mean depth of water in barge before test.	Mean depth of material in barge at end of test.	Mean depth of material pumped.	Quantity of material pumped.	Quantity per second.	Velocity of discharge, per second.	Mean depth of sand.	Quantity of sand.	Percentage of sand.	Sand pumped, rate per hour.	Work done per second, measured by material pumped.	Work done per second, measured by indicator cards.	Efficiency per centum.	Sand pumped per hour, per I. H.P.	Weight of a cubic foot of dry sand.	Percentage of voids.
	Feet.	Feet.	Feet.	Cu. ft.	Cu. ft.	Feet.	Feet.	Cu. ft.		Cu.yds.	Ft.-lbs.	Ft.-lbs.		Cu.yds.	Lbs.	
1..	0.487	2.783	2.296	5 874.8	73.07	11.59	0.332	840.8	14.3	1 394.0	190 438	277 970	68.5	2.76	98.5	37.2
2..	0.421	2.800	2.379	6 089.7	67.07	10.64	0.379	961.5	16.0	1 411.9	187 796	263 615	71.2	2.95	99.0	36.7
3..	0.767	2.967	2.200	5 629.1	53.46	8.48	0.352	892.0	15.8	1 129.5	159 043	267 410	59.5	2.32	105.5	32.8
4..	0.375	2.650	2.275	5 821.0	71.69	11.37	0.187	473.6	8.1	776.2	181 017	240 295	75.3	1.78	99.0	37.3 [2]
5..	0.417	1.967	1.550	3 966.0	66.66	10.57	0.347	878.8	22.2	1 967.4	192 064	281 710	68.2	3.84	103.5	35.7
6..	0.317	1.296	0.979	2 507.5	61.76	9.79	0.214	542.0	21.6	1 780.0	192 228	262 680	73.2	3.73	101.5	34.6
7..	0.367	1.617	1.250	3 198.4	49.43	7.84	0.270	683.8	21.4	1 410.9	159 721 [4]	.....	.....	.....	103.0	34.4 [3]
8..	0.290	1.850	1.560	3 991.6	59.40	9.42	0.436	1 101.0	27.6	2 184.5	191 194	265 430	72.0	4.53	105.0	34.0
9..	0.267	2.117	1.850	4 733.6	67.91	10.77	0.247	625.5	13.2	1 194.6	185 479	264 330	70.2	2.49	99.5	33.2
10..	0.345	1.583	1.238	3 167.7	32.46	5.15	0.263	666.0	21.0	909.6	121 928 [4]	.....	.....	.....	107.0	32.8 [5]
11..	0.379	2.067	1.688	4 319.1	67.07	10.64	0.495	1 253.2	29.0	2 595.2	207 079	279 125	74.2	5.11	106.0	36.3
	0.403	2.1543	1.7514	4 481.68	60.907	9.660	0.3202	810.75	19.11	1 523.09	187 370.9	266 951.7	70.26	3.28	102.5	35.0 [6]
SPECIAL TEST.																
12..	0.533	2.575	2.042	5 224.9	81.89	12.99	0.136	344 0	6.6	718.9	212 914	277 310	76.8	1.43	100.0	36.9 [7]

[1] Suction pipes: Two, 24 ins. diameter; length from mouth to pump = 48 ft. Discharge pipe: Diameter, 34 ins.; length from stern of dredge to valve in barge = 987.1 ft. Length from pump to valve in barge = 1 069 ft. Advance of dredge per revolution of winding engines = $\frac{1}{4}$ ft. [2] Experiment with light load. [3] No indicator cards were taken. [4] Not used in computing average. [5] Pipes sunk at test. No indicator cards were taken. [6] Average. [7] Jets not in operation

Dredge *Delta*.

The dredge *Delta* was constructed under contract with the New York Dredging Co., which sublet the construction of different parts to various manufacturers and builders of machinery. The contract price for this dredge was $124 940. It differs from the *Gamma* chiefly in having a mechanical agitator instead of jets, in its hoisting and hauling winches, and in the form of pump. Its capacity is also somewhat greater. Its construction was begun in June, 1896, and it was practically completed by the end of June, 1897. After the tests were finished, this dredge was used in removing sand bars below Cairo throughout the low-water season of 1897.

The hull is of steel, 175 ft. long, 38 ft. wide, and 8½ ft. deep. A fender 24 ft. long is carried around the suction, making the boat 199 ft. long over all. The bow and stern of the hull have short rakes, and the midship section is rectangular. The frames of the hull are 22 ins. apart between centers. Angles are used for the deck beams and Z-bars for the floors. There are two longitudinal bulkheads running the full length of the boat, and five cross-bulkheads. They are all made of $\frac{5}{16}$-in. plate, with double angles at top and bottom. All are watertight and have a syphon in each of the compartments. The thickness of the side plating of the hull is $\frac{3}{8}$ in. and of the other hull plating $\frac{5}{16}$ in. It is all laid fore and aft, is lapped and single-riveted, except on deck, where the seams are planed and butted and fastened with 6-in. butt-straps single-riveted. Cross-seams are similarly butted and riveted.

Special foundations of 12-in. I-beams are provided for sustaining the heavy machinery and boilers. The boat is provided with a cabin 156 ft. long, which protects the machinery and furnishes quarters for the crew. The operating room is at the forward end of the cabin, and is fitted with levers and brakes by means of which the boat is maneuvered.

The dredging pump is different from those on the dredges heretofore described, in the shape of the casing and the runner. The runner has five blades 22 ins. wide, and is 7 ft. in diameter. The edges run close to the casing, but the runner is not concentric with the casing, hence the outer ends of the arms are nearer one side of the casing than the other, the widest space being at the bottom, and the space being nearly cut off by a projection in the casing at the upper

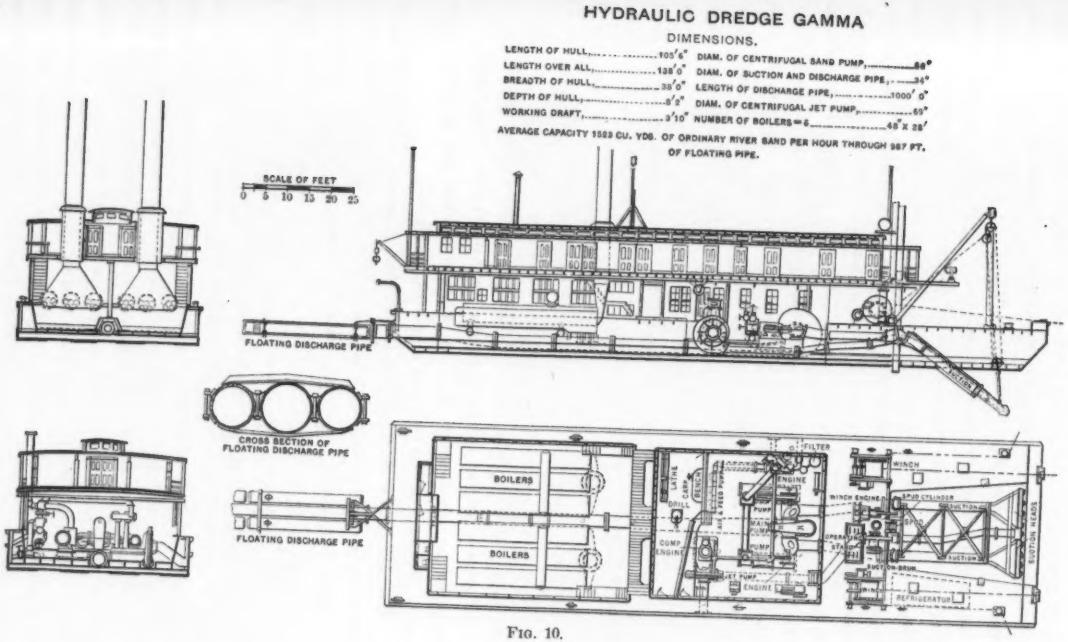

HYDRAULIC DREDGE GAMMA
DIMENSIONS.
LENGTH OF HULL,.....105'6"
LENGTH OVER ALL,.....138'0"
BREADTH OF HULL,.....38'0"
DEPTH OF HULL,.....8'2"
WORKING DRAFT,.....3'10"
DIAM. OF CENTRIFUGAL SAND PUMP,.....26"
DIAM. OF SUCTION AND DISCHARGE PIPE,.....24"
LENGTH OF DISCHARGE PIPE,.....1000' 0"
DIAM. OF CENTRIFUGAL JET PUMP,.....6"
NUMBER OF BOILERS = 6.....48" X 28'
AVERAGE CAPACITY 1523 CU. YDS. OF ORDINARY RIVER SAND PER HOUR THROUGH 987 FT. OF FLOATING PIPE.
SCALE OF FEET
0 5 10 15 20 25
FLOATING DISCHARGE PIPE
CROSS SECTION OF FLOATING DISCHARGE PIPE
FLOATING DISCHARGE PIPE
BOILERS
BOILERS
FILTER
WINCH
WINCH ENGINE
MAIN ENGINE
MAIN PUMP
COMP. ENGINE
JET PUMP ENGINE
REFRIGERATOR
SUCTION
DISCHARGE

FIG. 10.

side of the discharge opening. The shape of the pump runner and the upper half of the casing is shown in Fig. 1, Plate XXVI. The axis of the pump is parallel to the axis of the boat and lies over the center line of the same. The thickness of the sides of the casing is 2 ins., and that of the outer circumference is 3 ins. It is lined on the inner side with steel plates fastened with countersunk bolts. This lining can be renewed when worn out. The shaft of the runner is of forged steel $7\frac{1}{2}$ ins. in diameter and $7\frac{1}{2}$ ft. long. It is fitted to the runner by a taper joint secured by a cap nut and two keys. The shaft has one long bearing through the aft side of the casing. It is provided with water bushing under pressure to keep the sand out of the bearing. The sand pump is driven by a vertical, inverted, two-crank, compound-condensing engine, with 22 and 48-in. cylinders and 24-in. stroke. It is fitted with a piston and slide valve and has an adjustable cut-off for the piston valve. The cylinders are supported by two cast-iron back frames of box section, and four taper-steel front columns $2\frac{3}{4}$ and $3\frac{3}{4}$ ins. in diameter. The bed plate is of cast iron, box-girder pattern, 8 ft. 9 ins. long by 8 ft. $9\frac{1}{2}$ ins. wide over flanges, and $20\frac{1}{2}$ ins. deep from center of shaft. It has four babbitted journals 13 ins. long and $8\frac{1}{2}$ ins. in diameter. The steam chests are reached by means of a stairway and gallery. The usual accessories in the way of relief valves, drains, lubricators, etc., are provided. This engine was designed to develop 800 H.-P. at 140 revolutions per minute, with a boiler pressure of 160 lbs. and a vacuum of 25 ins.

The air pump and jet condenser has a steam cylinder 12 ins. in diameter, a water cylinder 18 ins., and 24-in. stroke. The condenser is mounted vertically over the water cylinder. The air cylinder is copper-lined 18 by 24 ins., and the plunger is packed with soft packing. The valve seats are brass and the valves are of hard rubber. A brass spray-cylinder throws the water out in jets.

The engine which drives the cutters is horizontal, two-cylinder and non-reversible, all attached to a sliding steel frame, which moves back and forth in guides as the cutter is raised or lowered. This is necessary because the shaft which drives the sprocket chain is not in the axis of motion on which the suction and cutter revolve. The whole engine, with its frame, follows the motion of the shaft, so that the gear and pinion are always engaged. To admit of this motion, the steam pipes are provided with slip joints. The cylinders of this engine are

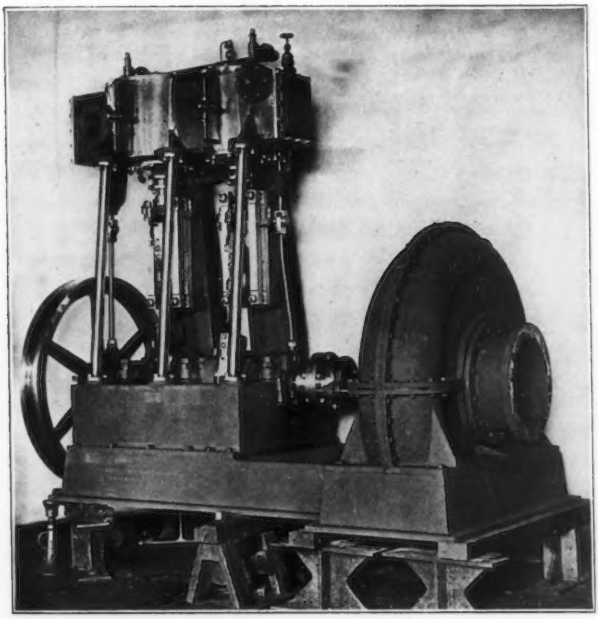


FIG. 1.

FIG. 2.

12¼ ins. in diameter and have a 15-in. stroke, with the locomotive type of slide valve. It operates the cutters through spur gears and a sprocket chain.

The fire pump is duplex, with two steam cylinders 8 ins. in diameter and two 5-in. plungers with a stroke of 10 ins. The suction is 5 ins. in diameter, and the delivery 4 ins. This pump furnishes water to all the journals where water pressure is used to keep out sand. The feed pump is also duplex, with two steam cylinders 7 ins. in diameter, two plungers 4½ ins. in diameter, with a stroke of 8 inches.

A pressure filter 7 ft. in diameter, with a capacity of about 65 galls. per minute is provided. A special 3 by 4-in. engine is used to revolve the cleaners.

A 7 by 9-in. vertical engine is provided to run the machines in the repair shop and the electric generator.

There are two winding drums located forward of the sand pump, one on the starboard and the other on the port side of the hull. These are 42 ins. in diameter and 42 ins. long, mounted on a 6-in. shaft with two bearings in the main pillow-blocks carrying a 48-in. gear wheel at one end, and an 84-in. gear wheel at the other. These drums are provided with clutches and brakes, and are driven by two independent double-cylinder, horizontal engines with 10-in. by 12-in. cylinders.

The ladder hoist for raising and lowering the suction, and the spud hoist for raising the spud, each have drums 24 ins. in diameter and 24 ins. long. The former is on the starboard, and the latter on the port side of the boat. The cables from these drums lead to the roof and thence out through sheaves to the ladder and spud. These drums are operated by the same engines that operate the winding drums.

Steam is supplied by four Heine safety boilers rated at 250-H.-P. each. These boilers have two shells 36 ins. in diameter and 19 ft. 4 ins. long; two water legs of flanged and riveted sheets held by hollow stay bolts; 140 lap-welded tubes 3½ ins. in diameter and 16 ft. long, and one submerged movable mud drum in each shell. These boilers are erected in two batteries on the main deck near the aft end of the boat. For each battery there is one stack, 68 ins. in diameter and 64 ft. high above the grate. The feed water is heated by passing through a heater with a shell 3 ft. 1½ ins. in diameter, fitted with 114 corrugated copper tubes 1½ ins. in diameter and 78 ins. long. This heater is situated in the center of the boat between the boilers and the

TABLE No. 5.—Capacity and Efficiency Tests of United States Dredge *Delta*.

Number of test.	Duration of test.	Conditions.[1]		Speed of cutters, revolutions per minute.	Forward movement of dredge per minute.	Main Engine and Pump.									
									I. H.-P.			Head.			
		Depth of water.	Depth of suction.			Steam pressure, pounds per square inch.	Vacuum in condenser, inches of mercury.	Revolutions per minute.	High-pressure cylinder.	Low-pressure cylinder.	Total.	Suction, feet of water.	Discharge, feet of water.	Velocity, feet of water.	Total, feet of water.
	Seconds.	Feet.	Feet.		Feet.										
1.....	77.0	6.0	11.2	7.7	3.9	159	24.0	150	498.5	536.6	1 035.1	17.0	46.4	4.1	67.5
2.....	62.5	5.8	11.2	9.0	4.4	156	23.3	151	.....	.....	.....	18.7	45.3	4.2	68.2[2]
3.....	71.5	7.0	12.1	7.6	6.0	156	23.0	149	.....	.....	.....	18.1	45.3	3.8	67.2[3]
4.....	79.0	6.7	12.1	9.3	3.8	156	23.0	151	496.7	534.2	1 030.9	19.2	54.5	2.3	76.0[4]
5.....	75.5	8.3	14.2	7.7	2.7	156	23.5	150	491.7	505.2	996.9	18.1	47.6	3.5	69.2
6.....	61.0	5.3	12.5	9.7	4.2	160	23.0	149	532.4	566.2	1 098.6	19.8	45.3	3.4	68.5[5]
7.....	59.25	.....	.....	.....	5.1	161	23.0	152	492.0	490.1	982.1	19.2	47.6	3.0	69.8[6]
8.....	61.0	7.0	12.7	9.4	4.4	160	24.2	149	461.9	456.3	918.2	17.0	47.6	3.7	68.3[7]
9.....	60.0	7.8	13.3	9.2	5.4	161	23.5	150	536.6	553.3	1 089.9	23.2	38.4	3.0	64.6
10.....	60.5	7.0	15.0	7.0	3.7	156	23.3	149	.....	.....	.....	19.2	43.0	3.5	65.7[8]
11.....	58.0	6.3	15.0	8.2	2.5	161	23.0	152	543.1	553.7	1 096.8	18.1	41.8	3.7	63.6
12.....	60.5	10.0	13.5	7.9	4.3	156	23.8	151	515.5	530.3	1 045.8	17.5	43.0	3.3	63.8
13.....	61.0	9.5	14.8	7.4	2.6	156	23.0	154	517.4	554.9	1 072.3	17.5	45.3	3.4	66.2[10]
14.....	72.0	10.0	14.5	7.9	2.8	156	23.0	154	522.3	546.9	1 069.2	18.1	46.4	3.5	68.0[11]
	65.63	7.44	13.24	8.30	3.99	157.9	23.33	150.8	509.8	529.8	1 039.6	18.62	45.54	3.46	67.61[12]
				7.96	3.95	157.6	23.31	151.1	514.6	533.9	1 048.5	18.61	44.55	3.55	66.71[13]
SPECIAL TESTS.															
15.....	53.0	10.5	13.5	9.6	5.2	156	22.8	146	511.0	523.3	1 034.3	21.5	33.8	5.3	60.6[14]
16.....	60.0	8.0	13.3	.....	3.8	161	23.2	149	490.4	501.9	992.3	18.1	38.4	3.9	60.4[15]

TABLE No. 5.—(*Continued*).

Number of test.	Measuring Barge. (Area of water = 2 558.7 sq. ft.; area of sand = 2 532.5 sq. ft.)										Efficiency.					
	Mean depth of water in barge before test.	Mean depth of water and sand in barge at end of test.	Mean depth of material pumped.	Quantity of material pumped.	Quantity per second.	Velocity of discharge, per second.	Mean depth of sand.	Quantity of sand.	Percentage of sand.	Sand pumped, rate per hour.	Work done per second, measured by material pumped.	Work done per second, measured by indicator cards.	Efficiency per centum.	Sand pumped per hour, per I. H.-P.	Weight per cubic foot of dry sand.	Percentage of voids in wet sand.
	Feet.	Feet.	Feet.	Cu. ft.	Cu. ft.	Feet.	Feet.	Cu. ft.		Cu. yds.	Ft.-lbs.	Ft.-lbs.		Cu. yds.	Lbs.	
1....	0.396	3.467	3.071	7 857.8	102.05	16.19	0.398	1 007.9	12.8	1 745.3	430 523	569 305	75.6	1.69	98.5	37.2
2....	0.417	2.958	2.541	6 501.7	104.03	16.50	0.300	759.8	11.7	1 620.9	443 428[9]	.....	.....	.....	76.5	37.2[2]
3....	0.338	3.088	2.745	7 026.2	98.27	15.59	0.471	1 192.8	17.0	2 224.3	412 734[9]	.....	.....	.....	94.5	37.2[3]
4....	0.496	2.850	2.354	6 023.2	76.24	12.09	0.427	1 080.5	17.8	1 823.7	362 140	566 995	63.9	1.77	98.5	34.0[4]
5....	0.383	3.167	2.784	7 123.4	94.35	14.96	0.208	526.8	7.4	928.0	408 064	548 295	74.4	0.93	104.5	35.2
6....	0.571	2.783	2.212	5 659.8	92.78	14.71	0.439	1 111.8	19.6	2 432.4	397 214	604 230	65.7	2.21	108.5	36.3[5]
7....	0.362	2.408	2.046	5 235.1	88.36	14.01	0.518	1 311.8	25.1	2 949.2	385 420	540 155	71.4	3.00	100.5	40.0[6]
8....	0.583	2.900	2.317	5 928.5	97.19	15.41	0.180	455.8	7.7	995.0	414 880	505 010	82.1	1.08	115.5	36.2[7]
9....	0.575	2.633	2.058	5 265.8	87.76	13.92	0.375	950.1	18.0	2 111.3	354 331	599 445	59.1	1.94	96.5	37.1
10....	0.429	2.667	2.238	5 726.4	94.65	15.01	0.576	1 457.7	25.5	3 212.4	388 656[9]	.....	.....	.....	110.5	33.4[8]
11....	0.450	2.650	2.200	5 629.1	97.05	15.39	0.317	802.8	14.3	1 853.2	385 773	603 240	63.9	1.69	100.5	37.5
12....	0.512	2.700	2.188	5 598.4	92.54	14.68	0.263	667.5	11.9	1 471.1	369 008	575 190	64.2	1.41	102.5	38.9
13....	0.342	2.567	2.225	5 693.1	93.33	14.80	0.224	567.3	10.0	1 240.0	386 152	589 765	65.5	1.16	96.5	35.5[10]
14....	0.421	3.100	2.679	6 856.3	95.23	15.10	0.215	544.7	7.9	1 000.9	404 727	588 060	69.0	0.94	112.5	35.4[11]
	0.4482	2.8524	2.4041	6 151.77	93.845	14.883	0.351	888.38	14.76	1 829.12	390 747.9	571 790.0	68.62	1.620	101.14	36.51[12]
	0.4205	2.8545	2.4341	6 228.48	95.238	15.105	0.3514	889.93	14.69	1 850.60	390 499.1	576 681.9	67.88	1.595	99.41	36.8[13]
SPECIAL TESTS.																
15....	0.308	2.716	2.408	6 166.5	116.35	18.45	0.242	613.3	9.9	1 542.9	440 675	568 865	77.5	1.49	92.5	33.4[14]
16....	0.467	2.817	2.350	6 012.9	100.22	15.90	0.227	574.0	9.5	1 277.5	378 330	545 765	69.3	1.29	110.5	34.9[15]

[1] Distance from pump to valve in barge = 1 104.5 ft. Distance from end of suction to pump = 84.6 ft. Forward movement of dredge per revolution of winding engines = $\frac{1}{12}$ ft. Ratio of speed of cutters to speed of cutter engine = $\frac{1}{12.9}$. [2] No indicator cards were taken. [3] No indicator cards were taken. [4] Test barge valve not completely open. [5] Test barge valve did not close and open completely. [6] Cutter machinery broke at test. [7] Test barge valve not completely open. [8] No indicator cards were taken. [9] Not used in computing averages. [10] In sand with a small percentage of gravel. [11] In sand with a small percentage of gravel. [12] Average. [13] Average, excluding tests Nos. 4, 6 and 8. [14] Discharge pipe 532 ft. long, using cutters. [15] Cutters removed from suction.

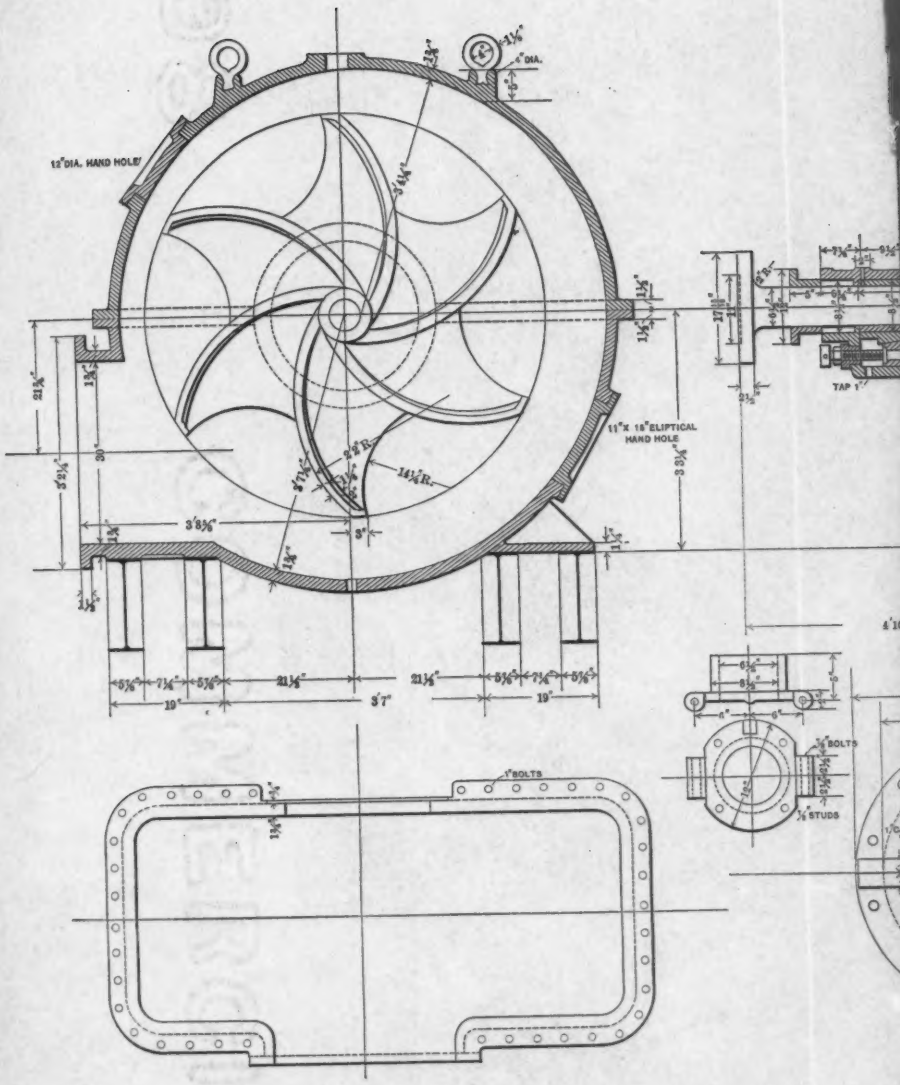
main engine. The main steam pipe is 6 ins. in diameter, the feed pipe 4 ins., and the drip, blow-off and safety pipes are 2 ins. in diameter.

The intake of the sand pump is from one pipe 34 ins. in diameter, entering in the axis of the pump at the forward side of the casing. This single pipe runs 25 ft. to the forward bulkhead and there branches into two pipes, each 24½ ins. in diameter, which separate and pass through the bow of the boat below the water-line 9 ft. apart. These two pipes turn to the right and left square along the outside of the bow and then turn forward again and each branch separates into two pipes 17½ ins. in diameter, which connect with the suction head. The whole is framed together so that the four pipes, suction head and cutters are raised and lowered together as one piece. Instead of a radial slip joint for the suction pipes, as used on the dredges already described, there is a vertical flanged joint in the horizontal part of each pipe next to the bow, and the revolving pins that sustain the weight of the aft end of the suction are placed in the prolonged axes of these pipes.

The cutter for loosening up the material is placed at the outer end of the suction head. It has twenty-two cast-steel wheel cutters, each having four blades mounted on a steel shaft 6⅞ ins. square. This shaft is driven by the cutter engine by means of two steel sprocket chains, at a rate of about eight revolutions per minute (see Fig. 2, Plate XXVI). The discharge outlet is on the starboard side of the casing near the bottom, and leaves the pump at right angles to the intake. After leaving the pump the pipe rises so that the center is slightly above the axis of the pump, and runs aft parallel to the side of the hull until it passes the main engine. Here it bends over to the center line of the hull, and the center of the pipe drops about 11 ins. below the water-line and runs straight aft under the boilers, through the stern, where the floating pipe is coupled on.

The floating discharge pipe is 1 000 ft. long, with the usual rubber couplings at intervals of 50 ft. There are pontoon floats on each side of this pipe, U-shaped in section, with the flat side closed, and they sustain the pipes in yokes which are firmly attached to the floats. There is a baffle plate at the end of the pipe line.

The dredge is provided with sixteen hydraulic piles, six of which are 10 ins. in diameter and 38 ft. long and ten are 6 ins. in diameter and 25 ft. long.


12" DIA. HAND HOLE
11" X 15" ELIPTICAL HAND HOLE
TAP 1"
1" BOLTS
⅞" BOLTS
⅛" STUDS

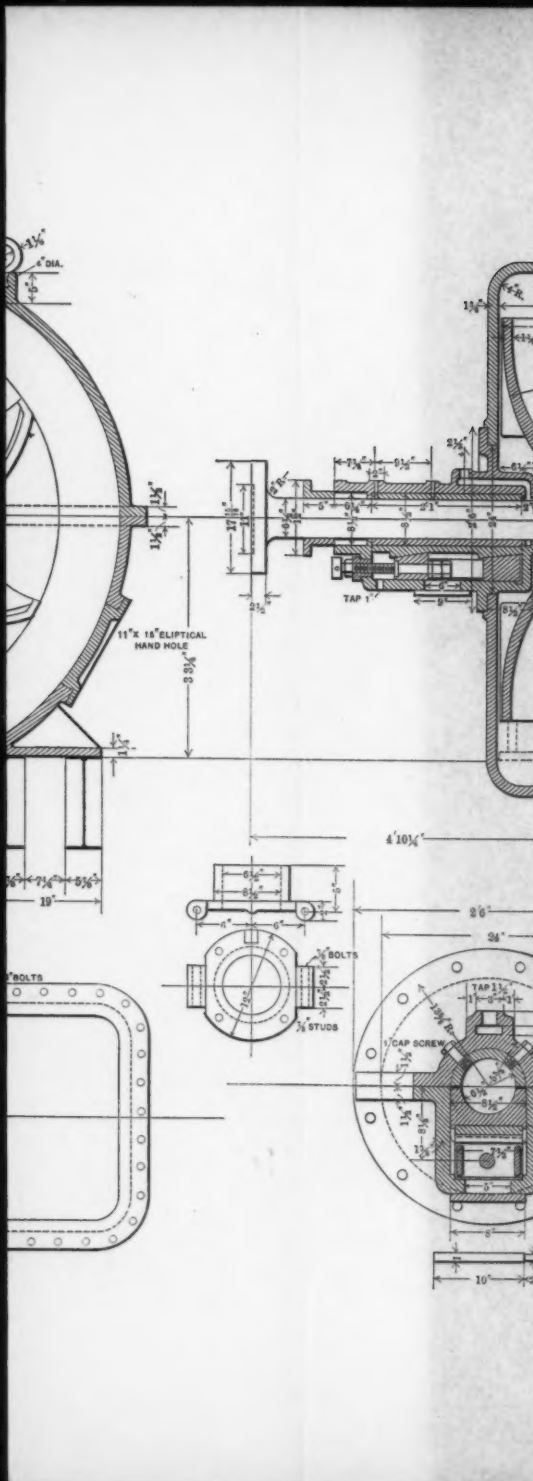

4" DIA.
11" X 18" ELIPTICAL HAND HOLE
TAP 1"
4'10¼"
19"
24"
BOLTS
STUDS
CAP SCREWS
TAP 1¼"
10"

PLATE XXIX.
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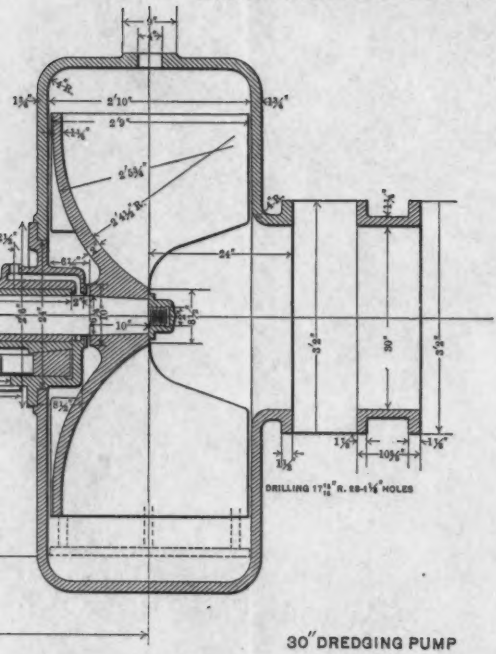
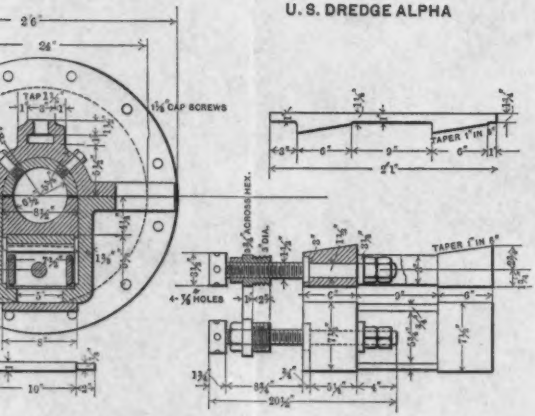
OCKERSON ON DREDGES AND DREDGING.



30" DREDGING PUMP
FOR
U. S. DREDGE ALPHA



The various parts of the winding machinery can be handled and moved by means of a 5-ton traveling crane. A traveler is also provided, with which to move the pump and main engine. The repair shop contains a screw-cutting engine-lathe, a drill press, a blacksmith's forge and a full set of tools.

The boat is equipped with one search light, two arc lights and 100 incandescent lamps.

The weights of the various parts of the dredge are about as follows:

Hull	489 500 lbs.
Main pump and engine	105 568 "
Cutter engines and machinery	45 000 "
Winding engines and machinery, with extras	47 000 "
Air, feed and fire pumps, with extras	11 900 "
Electric plant engines, dynamos, etc.	4 275 "
Heater, separator and filter	21 500 "
Derrick, ladder, travelers, tackle sheaves, bolsters, tools, etc	44 000 "
Capstans, spud, piping and fittings, deck fittings, etc.	42 000 "
Discharge and suction pipes pertaining to hull	51 300 "
Boilers, stacks, etc., complete	320 000 "
Cabin, complete	180 000 "
Spare parts for main pump, etc.	13 565 "
Total approximate weight	1 375 608 "

The weight of the floating pipe line is 221 477 lbs.

This dredge was launched on February 20th, 1897, and the tests were completed August 11th, 1897.

The results of the efficiency and capacity tests are given in Table No. 5.

Dredges *Epsilon* and *Zeta*.

The construction of the dredges *Epsilon* and *Zeta* was begun early in January, 1897. They were built under contract with the Springfield Boiler and Manufacturing Company, of Springfield, Ill. The work done by this company at its own shops was confined chiefly to the hulls, floating pipe lines, boilers, and other plate work. The pumps, engines, etc., were sublet to other manufacturers.

The stipulated capacity of these dredges is 1 000 cu. yds. of ordinary river sand per hour, dredged from a maximum depth of 15 ft., and delivered through 1 000 ft. of floating pipe.

The dredges are alike throughout, except that the *Epsilon* has water jet agitators and the *Zeta* has mechanical agitators. The contract price of the *Epsilon* is $102 000, and of the *Zeta* $106 000.

The hulls are of steel, 157 ft. long, 40 ft. wide and 7½ ft. deep. There is a well at the bow 35 ft. long, 18 ft. wide at the hull, and 22½ ft. wide at the forward end. There are two open spaces in the hull, one for the engine and pumps, and one for the boiler and coal bunkers, All other parts of the hull are decked over.

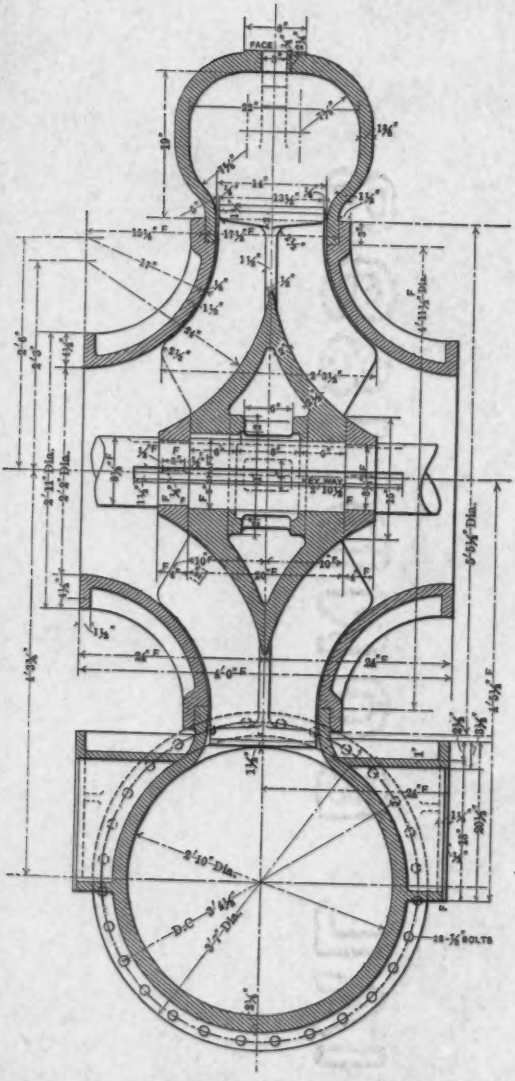
The floor beams are 12-in. steel channels, 25 lbs. per foot. The frames are 3 x 4-in. angle irons, 11 lbs. per foot, and are spaced 24 ins. between centers throughout the engine compartment, and 30 ins. for the other parts of the hull. There are ten 15-in. I-beam keelsons, the two outer ones weighing 55 lbs. per foot and the others 45 lbs. per foot. These keelsons are riveted to the floor beams.

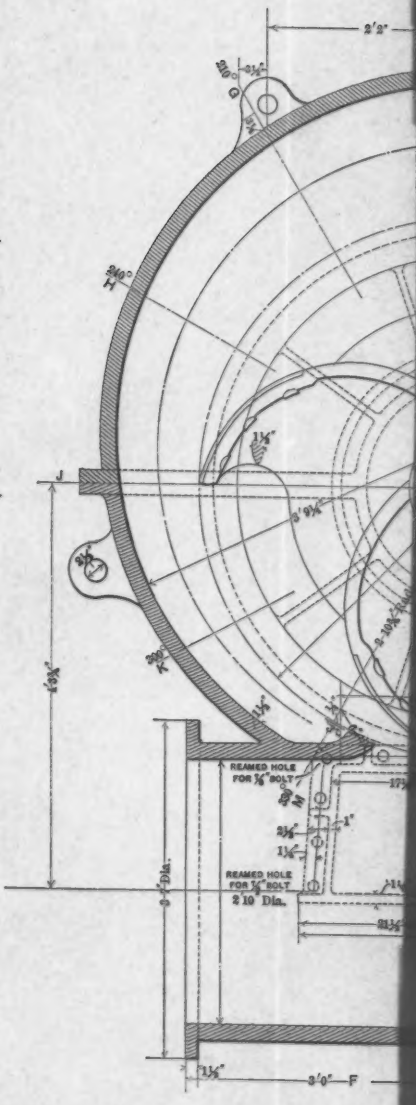
The greater part of the hull plating is ⅜ in. thick. The center strake of the bottom plating, the upper strake of the side plating and the bow end plates are ⅜ in. thick. The deck plating is ¼ in. thick. The butts of all outside plates are planed so as to fit closely. The longitudinal seams are lapped 2½ ins. and single riveted. The plates are butted on the transverse seams and riveted to butt straps ⅛ in. thicker than the plates.

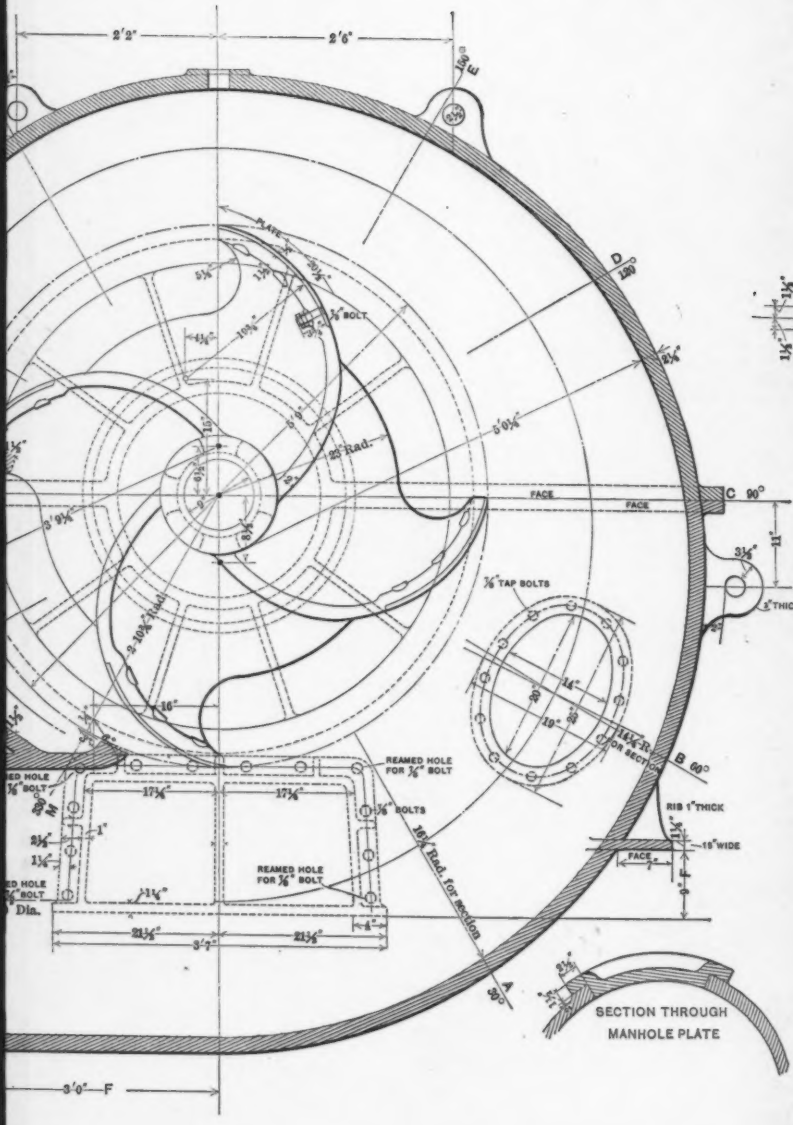
The hull is divided into eleven water-tight compartments by two longitudinal bulkheads and five cross bulkheads.

The frames in the engine and boiler pits are covered with $\frac{3}{16}$-in. plates. Special beams and angles are provided for supporting the machinery.

The main sand pump is located on the axis of the hull, in the forward part of the engine pit. It is similar in form to that on the *Gamma*. That is to say, it has a divided suction, consisting of two 24-in. pipes, admitting the water on both sides of the casing, and the shaft of the runner extends through the casing with a bearing at each side. The main bearings of the pump runner are protected from sand by means of a ring of water under pressure supplied by the fire pump. The discharge is from the bottom of the casing and is 32 ins. in diameter. The pump runner is 5 ft. 9 ins. in diameter and has seven


FACE
2'-10" Dia.
3'-4½" D.C.
3'-7" Dia.
28-⅞" BOLTS


REAMED HOLE FOR ⅞" BOLT
REAMED HOLE FOR ⅞" BOLT
2'-9" Dia.
2'-0" F


2'2"
2'6"
PLATE
⅞" BOLT
5'0½"
25" Rad.
FACE
FACE
C 90°
3⅛"
11"
2" THICK
⅛" TAP BOLTS
14"
10"
B 60°
REAMED HOLE FOR ⅞" BOLT
⅞" BOLTS
RIB 1" THICK
15" WIDE
FACE
18¼" Rad. for section
A 30°
SECTION THROUGH MANHOLE PLATE
3'0" F
Dia.

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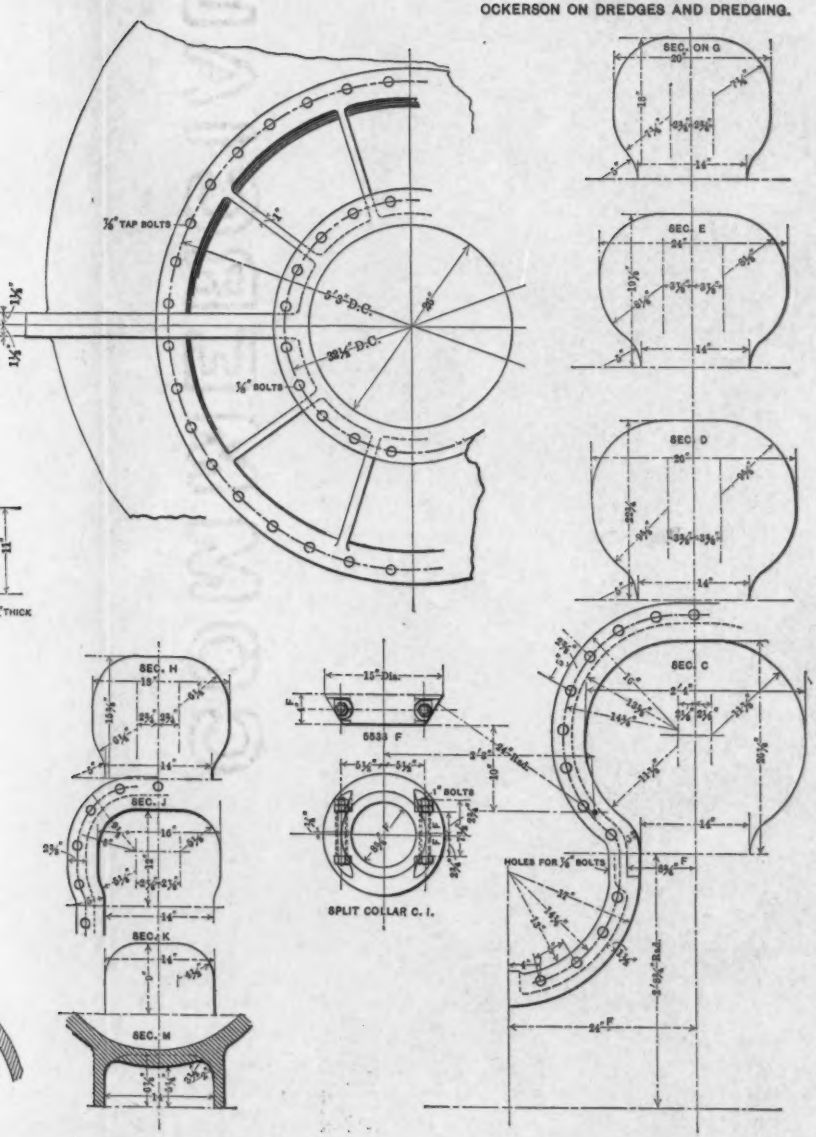


blades 11⅝ ins. wide at the outer ends. It is to be run at a speed of about 160 revolutions per minute. Pressure-gauges are provided to show the suction and delivery heads.

The main engines which operate the pump are connected to the ends of the shaft passing through the pump runner by means of flanged couplings. There is a tandem-compound engine at each end of the shaft, each having cylinders 16 and 26 ins. in diameter and an 18-in. stroke. The cranks are set at right angles with one another. These engines are balanced in a horizontal direction, and automatic governors are provided to regulate the speed. They are designed to develop 650 H.-P. at about 180 revolutions per minute, with a boiler pressure of 150 lbs. Plate XXVII show the engine in place. The engine sub-bases connect with and are bolted to the base of the pump casing, thus forming a common base for the whole. Table No. 6 shows the performance of these engines on the *Zeta*.

TABLE No. 6.—Showing Results of Tests of U. S. Dredge *Zeta*, at New Madrid, Mo., January, 1898. Size of Engine, 16 Ins. x 26 Ins. x 18 Ins.

Series.	Revolutions per minute.	Steam.	Suction head, water.	Delivery head, water.	Horse-Power.				Total horse-power.	Revolutions of cutter engines.
					Starboard engine.		Port engine.			
					High P.	Low P.	High P.	Low P.		
		Lbs.	Feet.	Feet.						
1.....	178	140	11.9	28.5	223	123	174	138	658	...
2.....	187	152	11.9	26.5	238	119	207	178	742	...
3.....	182	152	11.5	25.5	225	97	195	165	682	...
4.....	180	152	13.5	28.5	241	110	204	165	720	147
5.....	179	151	12.4	28.5	233	110	197	158	698	120
6.....	180	151	12.9	28.5	231	115	191	154	691	135
7.....	179	146	14.0	27.5	232	109	195	158	694	105
8.....	180	156	12.9	28.5	222	101	184	149	656	156
9.....	200	149	15.8	30.7	260	137	272	247	916	...

Notes.—

After taking Card No. 1, the governor was changed to a more sensitive position.

Shaft broke outside of main journal on starboard engine two minutes after cards were taken.

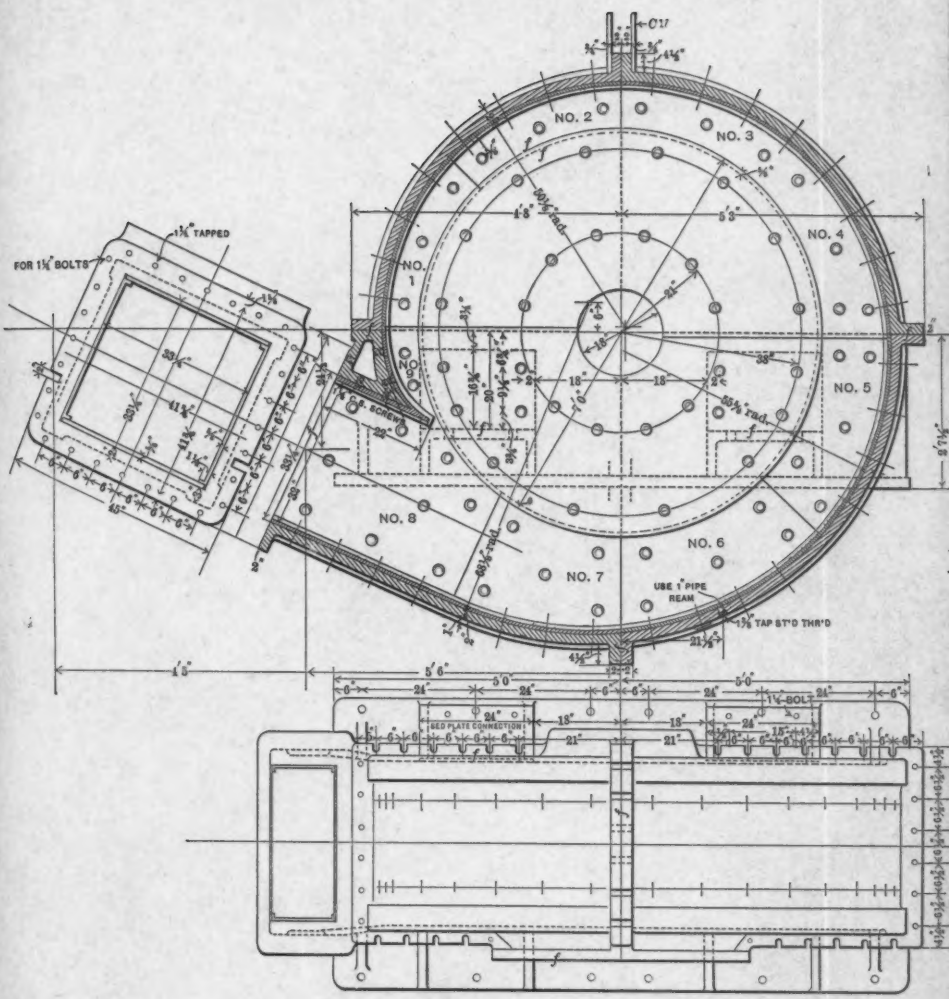
The *Epsilon* has a 15-in. centrifugal jet pump operated by a vertical cross-compound engine with cylinders 12 and 22 ins. in diameter and with 12-in. stroke. The engine is on the same base as the pump, and is directly connected with a flanged coupling. This pump is on the

starboard side at the rear end of the engine pit. The intake, 18 ins. in diameter, is on the side, and the discharge pipe, 15 ins. in diameter, leaves the casing at the bottom and leads to the pressure chamber at the suction head (Fig. 1, Plate XXVIII). Two boiler feed pumps are located in the engine pit opposite the jet pump, near the port side of the boat. The cylinders are 8 and 4½ ins. in diameter, and the stroke is 10 ins. There is also a fire pump, with cylinders 10 and 5 ins. in diameter, with a 10-in. stroke. These pumps are arranged with suitable cut-off valves so that they can be used together or singly, as may be desired.

The winding engines and the hoisting and hauling drums are located near the bow of the boat. The hauling engines for controlling the movements of the boat are located one on each side of the bow. The drums are 42 ins. long and 42 ins. in diameter, and hold about 1 200 ft. of ¾-in. wire rope in two laps. Each of these drums is operated by an 8 by 8-in. double-cylinder engine provided with a link reverse and suitable clutches and brakes giving fast or slow motion, as may be required. The suction hoist is situated a little to the port side of the center line of the hull. The drum is 14 ins. long, and 42 ins. in diameter. It is operated by a double engine with 8 by 8-in. cylinders. The spud hoist is located just behind the anchor spud and on the starboard side of the center line of the hull. It is also operated by an 8 by 8-in. double engine, and is used for raising or lowering the anchor spud. The drum is 21 ins. long and 42 ins. in diameter. The operator stands on an elevated platform behind the winches and controls their movements by means of vertical levers.

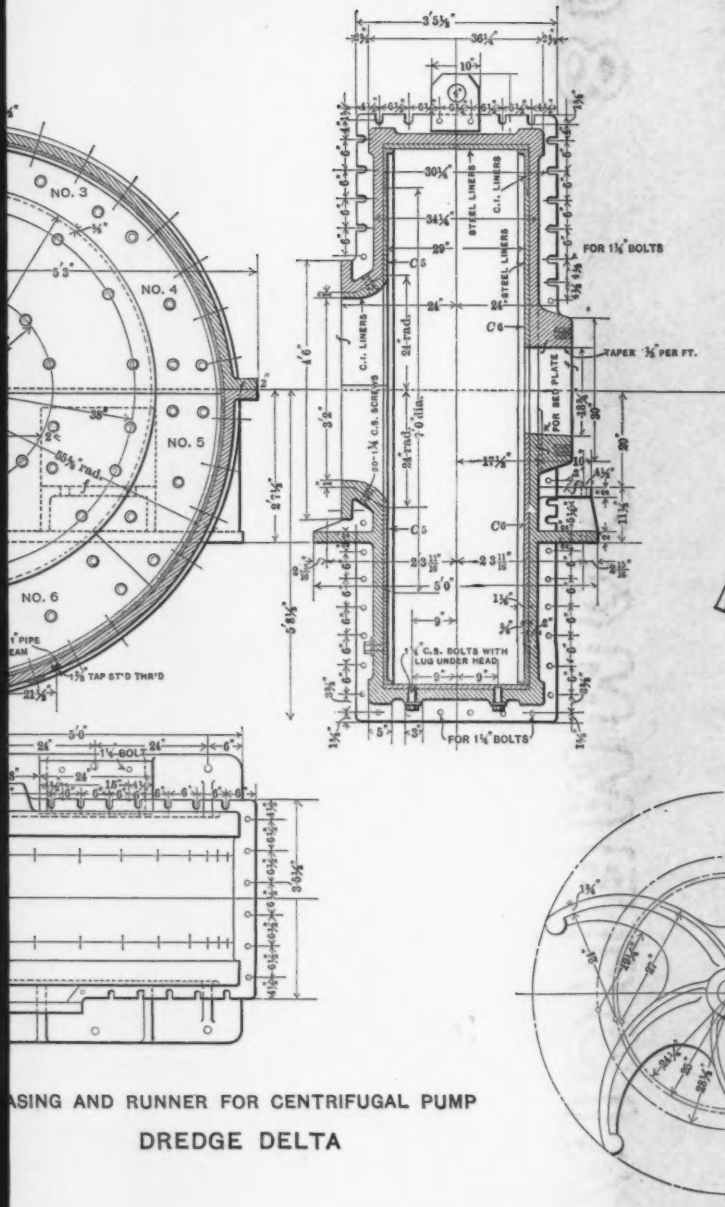
The repair shop is located between the operating room and the engine pit. It is provided with lathe, drill press, screw and bolt cutter, shaper, forge and an engine to run the several machines. A full set of machinist's and blacksmith's tools is also provided. In the same room is located the engine and direct-connected dynamo, furnishing light for all parts of the boat and also a powerful search light at the bow and two arc lights at the stern.

On the *Zeta* the jet pump is omitted and a mechanical agitator for stirring up the material is used. This agitator consists of a vertical scraper or harrow attached to the front end of the suction head which is given an up-and-down motion by means of a bell-crank. It is divi-



CASING AND RUNNER FOR C

DREDGE DI



ASING AND RUNNER FOR CENTRIFUGAL PUMP

DREDGE DELTA

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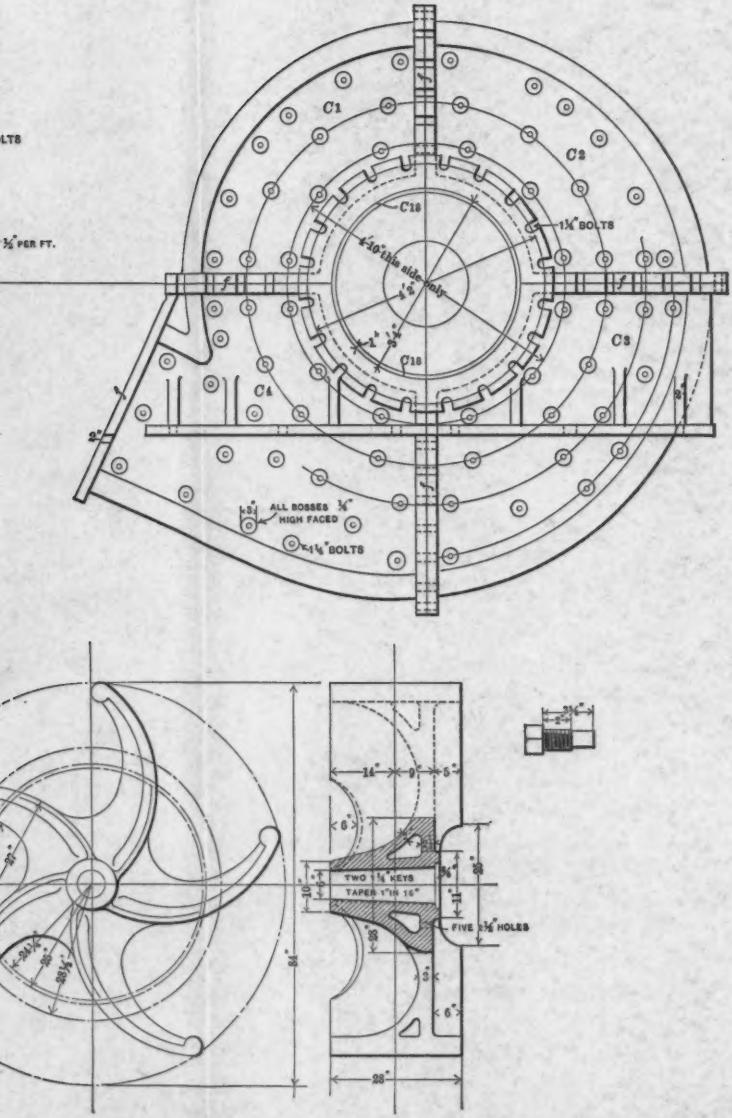


ded into two parts, which are suspended in front of the port and starboard suctions, respectively. A connecting rod or pitman extends from each agitator back to the rear end of the well, where it connects with a second oscillating crank operated by an engine with 10-in. by 14-in. cylinders. These engines are connected through gearing to a common shaft extending entirely across the boat. In order to lessen the danger of breakage from snags or other solid obstructions, a shearing pin is provided at the angle of the forward crank which is so arranged as to shear off before sufficient strain can come on the agitator to break it. Mechanically considered, its movements are quite satisfactory. In the tests it was demonstrated that the capacity of the pump with this agitator was not much over half the capacity of the pump with jet agitators. It will therefore be taken out, and jets will be put in.

Steam for the various machines described above is derived from six boilers located near the aft end of the boat. These boilers are 48 ins. in diameter and 28 ft. long, with three 11-in. and two 13-in. flues, and are designed for a working pressure of 140 lbs. They are arranged in two batteries so as to be operated separately or together. Each battery has a smokestack 44 ins. in diameter and 70 ft. high. The boilers are set below the main deck and rest on channel bars placed across the keelsons. The feed water is pumped through a heater which receives the exhaust steam from the main engines. A donkey boiler, 48 ins. in diameter and 9 ft. high, is also provided to furnish steam for the electric light and shop engines when the main boilers are not in use.

The two suction pipes run forward from the pump casing, separating gradually until 12 ft. apart at the bow. At this point a tight radial joint is provided, which connects the pipes in the hull with the pipes from the suction head, and admits of the vertical motion necessary for dredging at different depths. The suction can be lowered to a maximum depth of 15 ft. Outside the hull the two suctions are framed together rigidly and are handled as a single piece. The raising and lowering is accomplished by means of sheaves and tackle attached to a derrick frame located over the forward end of the suction well. A straining frame is provided so that when the suction is lowered to a suitable depth it can be locked; it thus relieves the tackle of the weight, and maintains the suction at a constant depth. Each part

TABLE No. 7.—Capacity and Efficiency Tests of United States Dredge *Epsilon*. March 14th to 17th, 1898.

Number of test.	Duration of test.	*Conditions.		Forward movement of dredge, per minute.	Main Engine and Pump.										Jet Pump.	
					Steam pressure, pounds per square inch.	Revolutions of main pump, per minute.	I. H.-P.					Head.				Revolutions per minute.	Head.
							Starboard.		Port.								
		Depth of suction.	Depth of water.				High-pressure cylinder.	Low-pressure cylinder.	High-pressure cylinder.	Low-pressure cylinder.	Total.	Suction, feet water.	Discharge, feet of water.	Velocity, feet of water.	Total, feet of water.		Discharge, feet of water.
	Seconds.	Feet.	Feet.	Feet.													
1	122.2	15.0	7.8	3.0	153	182	170.6	88.5	228.4	124.1	611.6	13.0	44.7	1.6	59.3	188	22.1
2	102.5	15.0	8.5	3.0	160	181	194.8	101.8	232.4	113.0	642.0	15.8	34.7	3.4	53.9	200	26.7
3	82.6	15.0	8.5	4.4	155	181	176.5	88.0	278.8	169.1	712.4	16.4	34.7	4.4	55.5	191	24.4
4	54.5	14.0	7.3	5.8	155	182	233.0	136.2	260.7	145.8	775.7	18.1	37.7	3.8	59.6	224	31.3
5	61.5	14.0	7.0	9.4	165	182	231.7	137.1	278.7	153.6	801.1	19.8	37.7	4.1	61.6	232	32.5
6	66.4	14.0	8.0	7.1	160	181	239.0	139.8	239.6	119.9	738.3	17.0	37.7	4.3	59.0	228	32.5
7	57.5	15.0	9.0	.....	162	182	242.6	137.1	229.8	107.6	717.1	14.7	36.7	5.2	56.6	140	35.6
Average, excluding tests Nos. 1 and 2	64.5	14.4	7.96	†6.67	159.4	181.6	224.56	127.64	257.52	139.20	748.92	17.2	36.9	4.36	58.46	203.0	31.26

* Suction pipes: Two 24 ins. in diameter; length from mouth to pump = 69 ft. Discharge pipe: diameter, 32 ins.; length from stern of dredge to valve in barge = 1 036 ft.; length from pump to valve in barge = 1 121 ft. † Average of Nos. 3 to 6.

TABLE NO. 7—(*Continued*).

Number of test.	MEASURING BARGE. (Area of water = 2 558.7 sq. ft.; area of sand = 2 532.5 sq. ft.).										EFFICIENCY.				Remarks.
	Mean depth of water in barge before test.	Mean depth of material in barge at end of test.	Mean depth of material pumped.	Total quantity of material pumped.	Quantity pumped, per second.	Velocity of discharge, per second.	Mean depth of sand.	Quantity of sand.	Percentage of sand	Sand pumped, rate per hour.	Work done per second, measured by material pumped.	Work done per second, measured by indicator cards.	Efficiency, per centum.	Sand pumped per hour, per I. H.-P.	
	Feet.	Feet.	Feet.	Cu. ft.	Cu. ft.	Feet.	Feet.	Cu. ft.		Cu. yds.	Ft.-lbs.	Ft.-lbs.		Cu. yds.	
1	0.600	3.333	2.733	6 992.9	57.22	10.2	0.274	693.9	9.9	757.1	212 072	336 380	63.0	1.24	Mud lumps in barge, not average material.
2	0.417	3.700	3.283	8 400.2	81.95	14.7	0.217	549.6	6.5	714.9	276 069	353 100	78.2	1.11	Mud lumps in barge, not average material.
3	0.433	3.483	3.050	7 804.0	94.48	16.9	0.419	1 061.1	13.6	1 712.8	327 728	391 820	83.6	2.40	Medium fine sand.
4	0.750	2.617	1.867	4 777.1	87.65	15.7	0.464	1 175.1	24.6	2 874.9	326 496	426 635	76.5	3.71	Medium fine sand.
5	0.300	2.467	2.167	5 544.7	90.16	16.4	0.565	1 430.9	25.8	3 102.2	347 116	440 605	78.8	3.87	Medium fine sand.
6	0.500	2.900	2.400	6 140.9	92.48	16.6	0.555	1 405.5	22.9	2 822.3	341 020	406 065	84.0	3.82	Medium fine sand.
7	0.367	2.667	2.300	5 885.0	102.35	18.3	0.384	972.5	16.5	2 255.1	362 063	394 405	91.8	3.14	Medium fine sand.
Average, excluding tests Nos. 1 and 2.	0.470	2.8268	2.3568	6 030.34	93.424	16.78	0.4774	1 209.02	20.68	2 553.46	340 884.6	411 906.0	82.9	3.388	

TABLE No. 8.—Capacity and Efficiency Tests of United States Dredge *Zeta*. March 21st to 24th, 1898.

Number of test.	Duration of test.	* Conditions.		Forward movement of dredge per minute.	Revolutions of cutter engine per minute.	Main Engine and Pump.							Head.			
						Steam pressure, pounds per square inch.	Revolutions of main pump per minute.	I. H.-P.								
								Starboard.		Port.						
		Depth of suction.	Depth of water.					High-pressure cylinder.	Low-pressure cylinder.	High-pressure cylinder.	Low-pressure cylinder.	Total.	Suction, feet of water.	Discharge, feet of water.	Velocity, feet of water.	Total, feet of water.
	Secs.	Feet.	Feet.	Feet.												
1	62.0	14	7.5	4.8	120	145	182	224.5	137.1	197.2	159.6	718.4	13.0	34.7	4.5	52 2
2	60.0	13	7.5	6.0	186	150	182	218.3	120.6	197.5	152.7	689.1	12.4	35.7	3.3	51.4
3	69.6	13	6.0	4.0	155	146	182	225.2	122.3	189.3	141.4	678.2	10.2	35.7	4.2	50.1
4	70.0	14	8.0	3.2	183	146	181	215.4	119.1	186.7	139.8	661.0	10.7	35.7	4.9	51.3
5	61.6	14	8.5	5.0	180	144	180	222.7	129.6	191.5	144.2	688.0	11.3	33.7	4.2	49.2
Average	64.64	13.6	7.5	4.6	164.8	146.2	181.4	221.22	125.74	192.44	147.54	686.94	11.52	35.1	4.22	50.84

* Suction pipes: Two, 24 ins. in diameter; length from mouth to pump = 69 ft. Discharge pipe: Diameter, 32 ins.; length from stern of dredge to valve in barge = 1 036 ft.; length from pump to valve in barge = 1 121 ft.

TABLE No. 8—(*Continued*).

Number of test.	Measuring Barge. (Area of water = 2 558.7 sq. ft.; area of sand = 2 532.5 sq. ft.)										Efficiency.				Remarks.
	Mean depth of water in barge before test.	Mean depth of material in barge at end of test.	Mean depth of material pumped.	Total quantity of material pumped.	Quantity pumped per second.	Velocity of discharge per second.	Mean depth of sand.	Quantity of sand.	Percentage of sand.	Sand pumped, rate per hour.	Work done per second, measured by material pumped.	Work done per second, measured by indicator cards.	Efficiency, per centum.	Sand pumped per hour, per I. H.-P.	
	Feet.	Feet.	Feet.	Cu. ft.	Cu. ft.	Feet.	Feet.	Cu. ft.		Cu yds.	Ft.-lbs.	Ft.-lbs.		Cu. yds.	
1.....	0.417	2.717	2.300	5 885.0	94.92	17.0	0.345	873.7	14.8	1 878.9	309 677	395 120	78.4	2.62	Medium fine sand. Sheared four pins before test was obtained.
2.....	0.650	2.567	1.917	4 905.0	81.75	14.6	0.231	585.0	11.9	1 300.0	262 622	379 005	69.4	1.89	Medium fine sand. Test made after shearing four pins, only one agitator running.
3.....	0.317	2.817	2.500	6 396.8	91.91	16.5	0.274	693.9	10.8	1 329.4	287 798	373 010	77.2	1.96	Medium fine sand. Test made after shearing two pins.
4.....	0.433	3.150	2.717	6 952.0	99.31	17.8	0.222	562.2	8.1	1 070.9	318 413	363 550	87.6	1.62	Medium fine sand. Test made after shearing five pins and with only one agitator running.
5.....	0.433	2.650	2.217	5 672.6	92.09	16.5	0.227	574.9	10.1	1 244.4	283 177	378 400	74.8	1.81	Medium fine sand. No pins sheared.
Average...	0.450	2.7802	2.3302	5 962.3	91.996	16.48	0.2598	657.94	11.14	1 364.72	292 336	377 817	77.5	1.98	

of the suction head is 10 ft. long, making the suction 20 ft. wide over all.

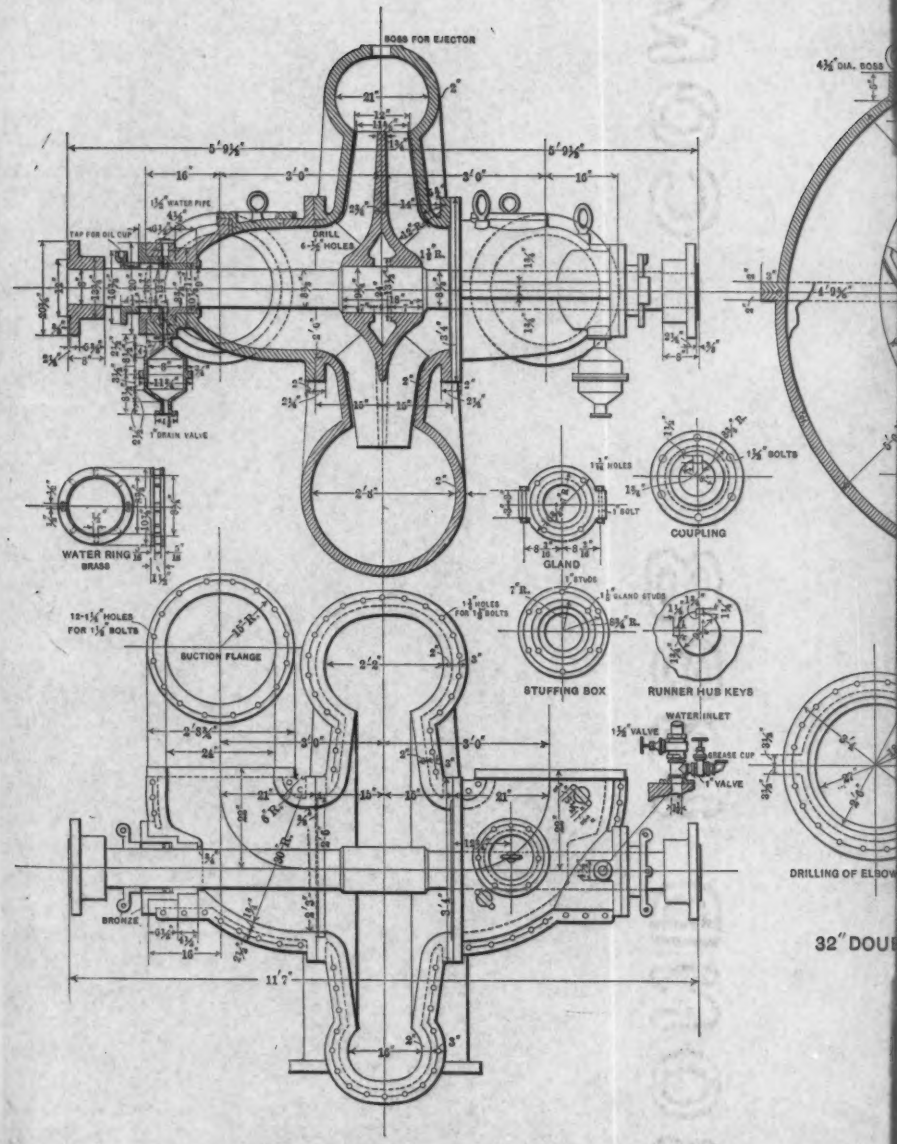
The *Epsilon* suction head has a pressure chamber on the under side at the front end connecting with the jet pump. Ten 3-in. jet nozzles are screwed into the front side of this pressure chamber and serve to loosen and stir up the sand and induce the flow of material to the suction.

The discharge pipe passes straight aft from the pump between the two central keelsons, and rests on the floor beams for a distance of about 52 ft. From this point it rises gradually for a distance of 22 ft. until the center of the pipe is 4 ft. above the bottom of the boat. Then it runs horizontally straight out through the stern, projecting far enough to couple on the floating pipe line. The pipe is flattened out near the pump casing so as to depress it below the water-line and thus facilitate priming, which is done by using a steam syphon at the top of the casing. The floating discharge pipe is similar to those previously described, except that greater buoyancy is provided, and the shape of the float is somewhat flatter. Fig. 2, Plate XXVIII, shows some of these pipes under construction and gives a good idea of their form. They are built in 50-ft. lengths.

Traveling cranes are provided for the easy handling of the machinery of the engine room and the hoists; and there is one steam capstan at each corner of the dredge. Steam syphons are provided for all the water-tight compartments. Six 10-in. and ten 7-in. mooring piles of the usual form are provided for each dredge.

A velocimeter is provided for showing the velocity of flow in the discharge pipe. This consists of two vertical tubes which pierce the discharge pipe. They are set in the vertical plane passing through the longitudinal axis of the discharge pipe. About 5 ins. below the upper inner surface of the pipe, ¼-in. tubes, 6 ins. long, are inserted horizontally; the one nearest the pump being open toward the pump to receive the pressure of flow and the other turned in the opposite direction. The upper ends of the vertical tubes connect with glass tubes attached to suitable scales. The difference in the height of the columns of water in the two tubes, when water is flowing through the discharge pipe, gives results from which the velocity of flow can be deduced.

Weighing apparatus, designed to show the percentage of solid matter passing through the discharge pipe, is also provided. To ac-


BOSS FOR EJECTOR
4¾" DIA. BOSS
5'-9½"
16"
2'-0"
3'-0"
1½" WATER PIPE
TAP FOR OIL CUP
DRILL 6-⅞" HOLES
1" DRAIN VALVE
WATER RING BRASS
1¼" HOLES
1⅛" BOLTS
1" BOLT
COUPLING
GLAND
1" STUDS
1½" GLAND STUDS
STUFFING BOX
RUNNER HUB KEYS
18-1¼" HOLES FOR 1⅛" BOLTS
SUCTION FLANGE
WATER INLET
1½" VALVE
GREASE CUP
1" VALVE
BRONZE
11'7"
DRILLING OF ELBOW
32" DOU

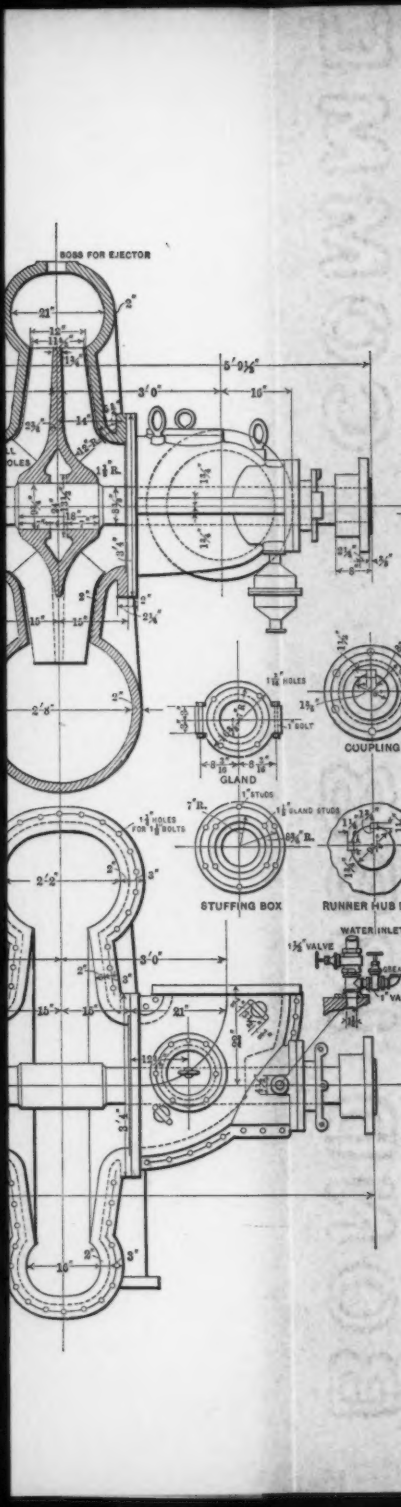
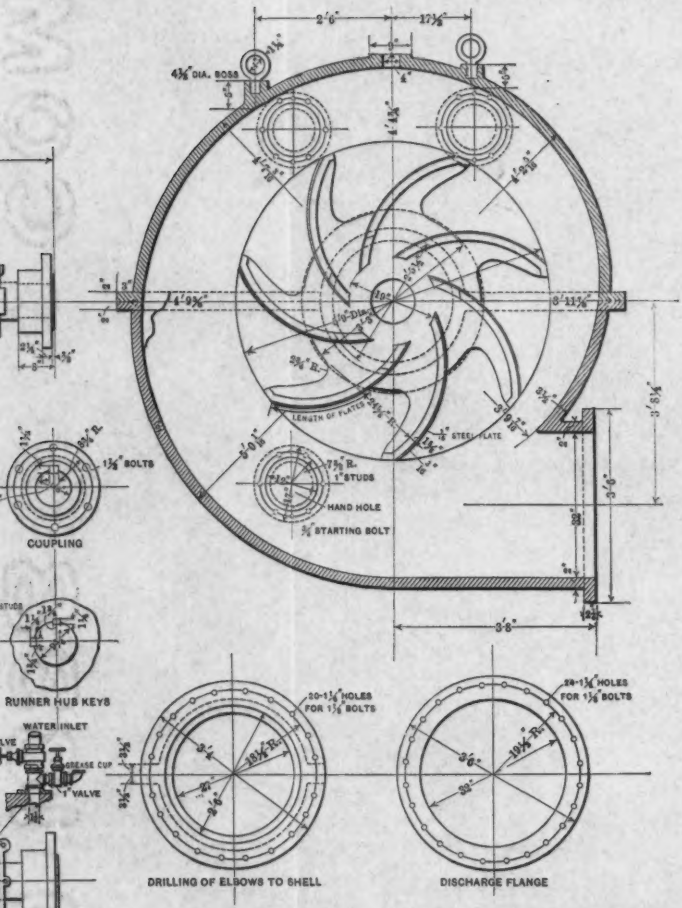

BOSS FOR EJECTOR
GLAND
COUPLING
STUFFING BOX
WATER INLET

PLATE XXXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 838.
OCKERSON ON DREDGES AND DREDGING.



32" DOUBLE SUCTION DREDGING PUMP

complish this, a suitable length of the pipe is connected at each end by rubber thimbles, which leaves the joints flexible. One end of this pipe is then supported by a weighing apparatus properly counter-balanced. An indicator is located where it can be readily seen by the engineer. The pointer is set so that it reads zero on the dial when water only is pumped. When sand is pumped the pointer will show on the dial the weight of the same at any moment, and consequently the percentage of solid matter.

Both dredges have cabins, for the protection of the machinery and to provide quarters for the crew. On the main deck the house is 34 ft. wide, 113 ft. long and 12 ft. high. Above this is the cabin proper, 32 ft. wide, 109½ ft. long and 9 ft. high, built and arranged as in ordinary steamboat practice. There are ample accommodations for a crew of fifty.

The weights of the various parts of each of these dredges are about as follows: Hull, 442 388 lbs.; main pump and engines, 117 060 lbs.; cutter engine and agitator, *Zeta*, 25 000 lbs.; jet pump and engine *Epsilon*, 19 010 lbs.; winding engines and machinery, 33 436 lbs.; fire and feed pumps, 8 100 lbs.; heater, 4 925 lbs.; electric plant, 4 200 lbs.; derrick, A-frame, travelers, sheaves, pipes and fittings, deck fittings, capstans, etc., 37 500 lbs.; discharge and suction pipes pertaining to hull, *Epsilon*, 54 447 lbs.; same for *Zeta*, 51 509 lbs.; boilers, stacks, etc., complete, 195 000 lbs.; cabin, complete, 120 000 lbs.; total approximate weight of each dredge, 1 057 118 lbs.; weight of floating pipe line, 325 000 lbs.

The efficiency tests of these dredges were begun about the middle of January. Owing to delays occasioned by high water and some minor modifications that were required, the capacity tests were delayed until the latter part of March, 1898.

The results of these tests are given in Tables Nos. 7 and 8.

The specifications and plans of all the dredges of the Mississippi River Commission have been prepared under the direction and subject to the approval of the Committee on Dredges, consisting of Major Thomas H. Handbury, Corps of Engineers, U. S. A.; Henry Flad, M. Am. Soc. C. E., and B. M. Harrod, Past-President, Am. Soc. C. E.

The dredges *Gamma*, *Delta*, *Epsilon* and *Zeta* were constructed under the direction of Captain H. E. Waterman, Corps of Engineers, U. S. A.

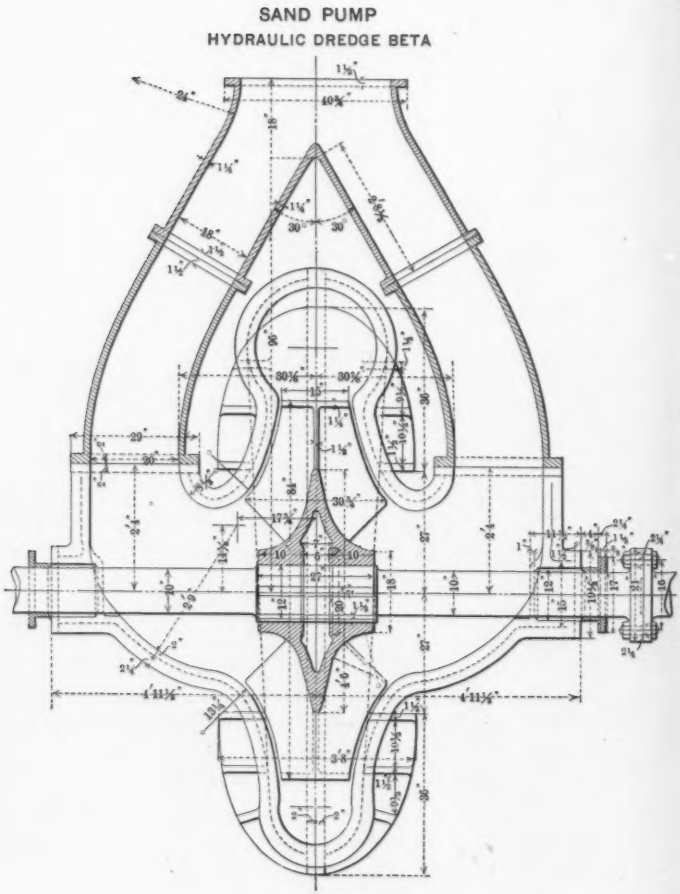


FIG. 11.

SAND PUMP
HYDRAULIC DREDGE BETA

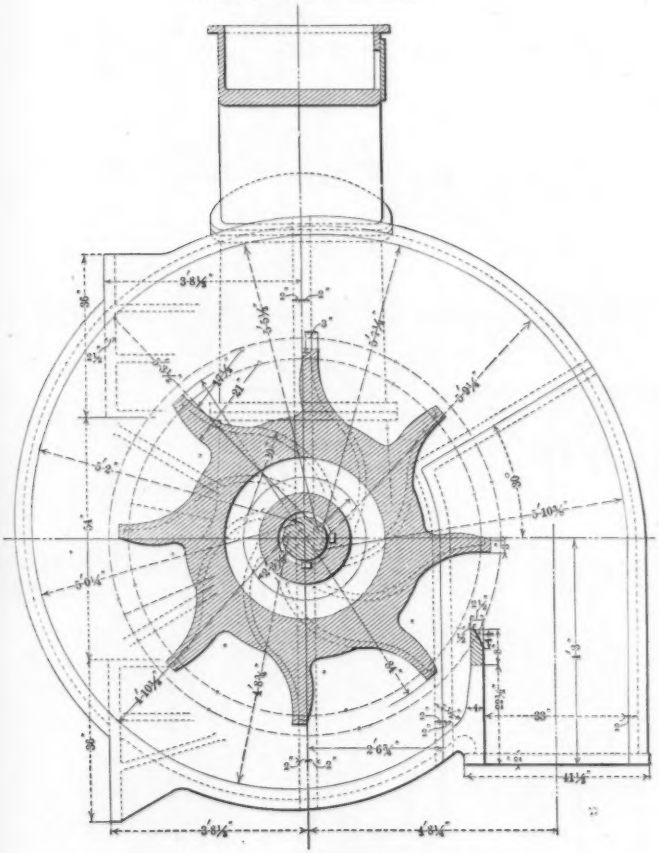


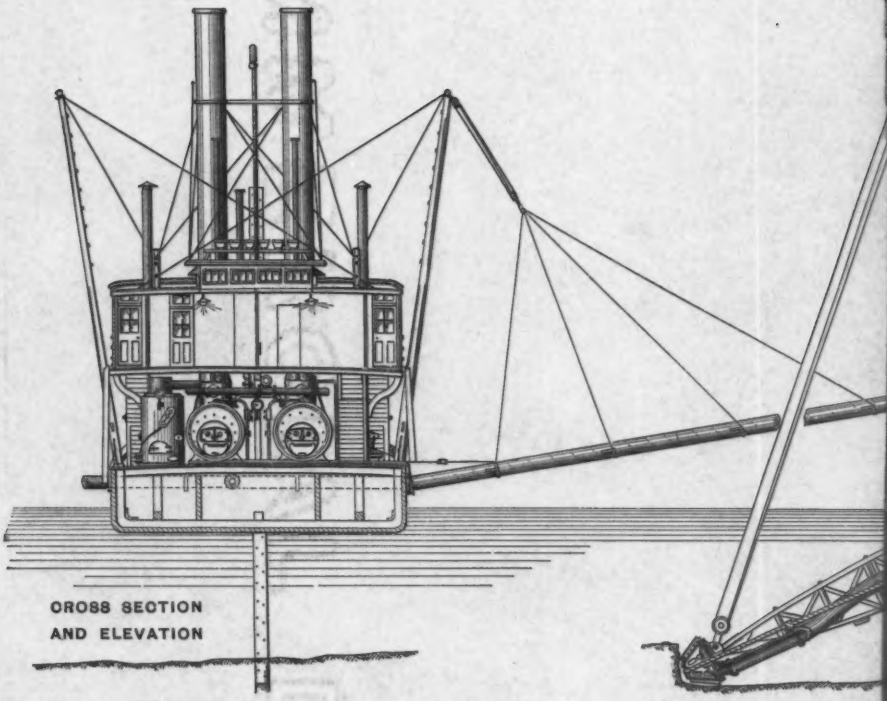
FIG. 12.

TABLE No. 9.—PRINCIPAL FEATURES OF U. S. DREDGE BOATS OPERATING ON THE MISSISSIPPI RIVER BELOW CAIRO, ILL.

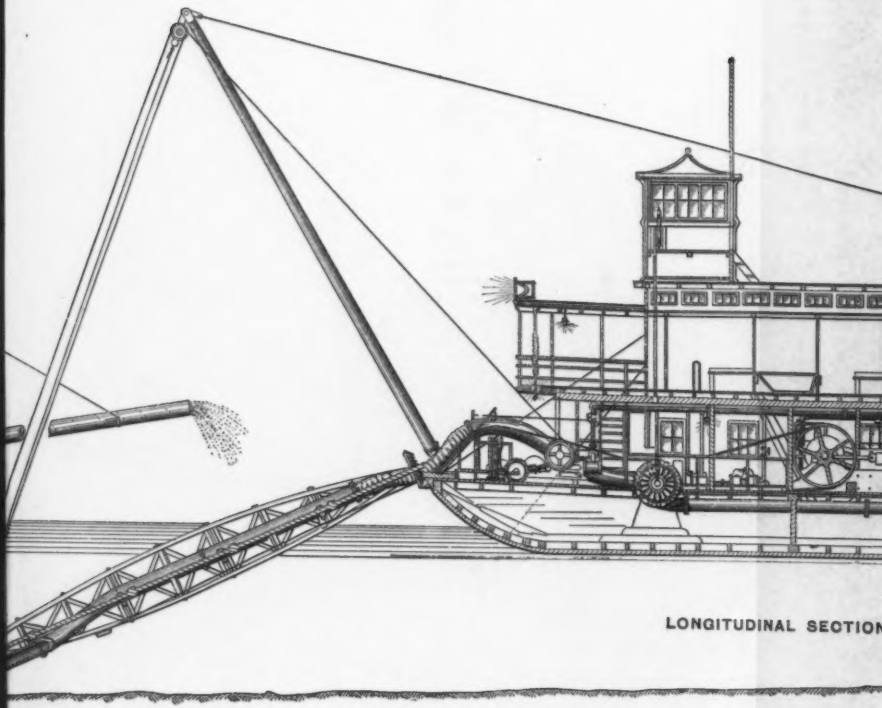
Name of Dredge.	*Alpha.*	*Beta.*	*Gamma.*	*Delta.*	*Epsilon.*	*Zeta.*
When built	1893.	1895.	1897.	1897.	1897-98.	1897-98.
Cost	$87 000	$217 000	$86 000	$125 000	$102 000	$106 000
Capacity in cubic yards of sand per hour	600	2 000	800	1 000	1 000	1 000
Hull—Kind	Wood.	Steel.	Steel.	Steel.	Steel.	Steel.
Size	140' x 36' x 8'	172' x 40' x 7' 2"	138' x 38' x 8'	175' x 38' x 8' 4"	157' x 40' x 7' 9"	157' x 40' x 7' 9"
Working draft	4' 10"	6' 6"	4' 3"	4' 3"	4'	4'
Main engines—Number	1	2	1	1	2 coupled	2 coupled
Kind	Cd. non-cond.	4 cyl. trpl. exp. 2 crank cond.	Horiz. cross comp. cond.	Vertical comp. cond.	Horiz. tandem coup. non-cond.	Horiz. tandem coup. non-cond.
Size	15"-27" x 20"	20½"-33"-38" -38" x 24"	18"-22½" x 22"	24"-48" x 24"	16"-26" x 18"	16"-26" x 18"
Horse-power	300	2 000	500	800	650	650
Revolutions per minute	140	135	150	150	180	180
Kind of condenser	None.	Jet.	Jet.	Jet.	None.	None.
Main dredging pumps—Centrifugal	1	2	1	1	1	1
Diameter of runner	6'	7'	5' 9"	7' x 28" wide.	5' 9"	5' 9"
Kind of suction	Side.	Divided.	Divided.	Side.	Divided.	Divided.
Diameter of suction	30"	Six 19½-in.	Two 24-in.	Four 17½-in.	Two 24-in.	Two 24-in.
Discharge pipes—Number	1	2	1	1	1	1
Discharge pipes—Size	30"	33"	34"	34"	32"	32"
Suction head in feet of water	7	18	9	18	12	12
Delivery head in feet of water	20	29	37	45	28	28
Velocity—Feet per second	10	14	10	15	13	13
Sand agitators	6 jets 2½" diam.	6 vert. cutters.	9 jets 2½" diam.	Horiz. cutters.	10 jets 3" diam.	Oscillating rake.
Engines, kind	Cd. non-cond.	Cross cd. non-cond.	Comp. cond.	2 simple.	Vert. comp. non-cond.	2 simple.
Engines, size		14½"-29" x 18"	12"-22" x 14"	12¼" x 15"	12"-22" x 12"	Each 12" x 16"
Engines, revolutions per minute	190	120	160		200	180
Cutters, revolutions per minute		12		5		60 double strokes
Engines, horse-power	125		200		150	80
Jet pumps	Centrifugal.		Centrifugal		Centrifugal.	
Suction and discharge diameter	10"		18"		18" and 15"	
Suction head	6		7		5	
Delivery head	20'		28'		30'	
Boilers—Number	4	4	6	4	6	6
Kind	Miss. River.	Heine 375 H.-P.	Miss. River.	Heine 250 H.-P.	Miss. River.	Miss. River.
Size	42" x 28'		48" x 28' Five 11" flues.		48" x 28' Three 11" & Two 13" flues.	48" x 28" Three 11" & Two 13" flues.
Pressure used	135 lbs.	165 lbs.	140 lbs.	155 lbs.	150 lbs.	150 lbs.
Coal used per 24 hours	500 bu.	2 088 bu.	400 bu.	1 200 bu.		
Total cost of running dredge per day	$98.70	$221.63	$100.51	$111.76		

Cost of steam tender per day, $37. Cost of pile sinker per day, $13.

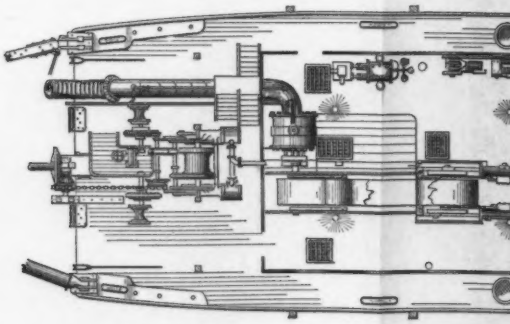
Cost of steam tender per day, $87. Cost of pile sinker per day, $18.

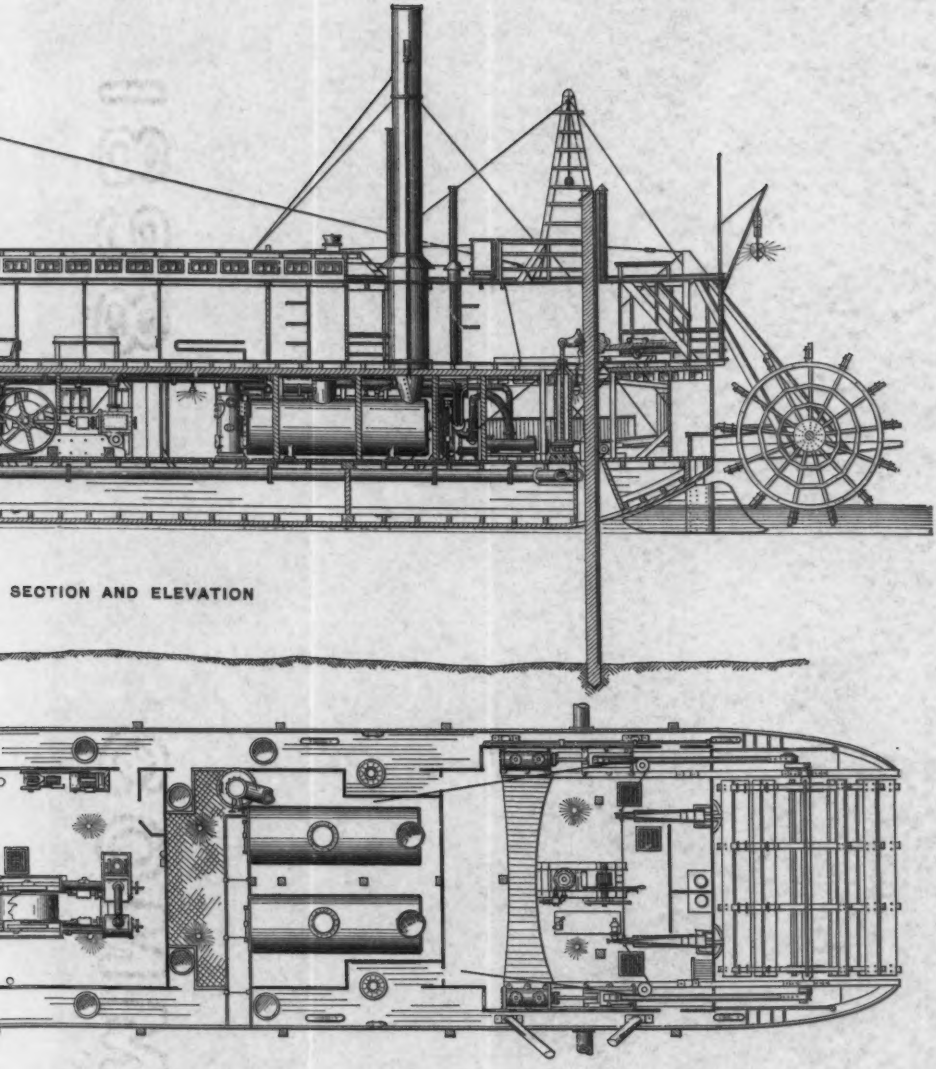


DREDGE RAM



LONGITUDINAL SECTION





SECTION AND ELEVATION

Another dredge has been designed for work on the river below Cairo, and the contract for its construction has been let. This will be a single-pump dredge, similar in form to the *Epsilon*, but will be provided with side wheels and propelling machinery. The contract price for this dredge is $94 970.

Perhaps the most important feature of a hydraulic dredge is its pump. As there is a wide variance in practice as to the form and size of pump runners, it will probably be interesting to show the details of the several pumps now in use on the Mississippi River. These are shown in the following plates and figures: *Alpha*, Plate XXIX; *Beta*, Figs. 11 and 12; *Gamma*, Plate XXX; *Delta*, Plate XXXI; *Epsilon* and *Zeta*, Plate XXXII.

The general features of the dredges now in use on the Mississippi River below Cairo are summarized in Table No. 9.

Two dredges for use on the Mississippi River between the Missouri and Ohio Rivers are now under construction and are practically completed. They were designed and constructed under the direction of Major Thomas H. Handbury. They will be ready for use during the next low-water season. It is expected that a navigable channel 6 ft. deep can be maintained with these dredges, aided by the temporary jetties and the jet dredge.

The hulls of these dredges are of steel, 160 ft. long and 40 ft. wide, with 6½ ft. depth of hold. Their working draft will be about 3½ ft. The framing of the hulls consists of 12-in. channels weighing 25 lbs. per foot for floor beams; side frames 3 x 4-in. angles, 11 lbs. per foot, riveted to web of floor beams. The above frames are spaced 12 ins. in the engine and boiler pit, and 30 ins. through the remainder of the hull. There are 10 keelsons, running the entire length of the boat, made of 15-in. steel I-beams. The outboard beams weigh 55 lbs. per foot and the intermediates 45 lbs. per foot. Each keelson is riveted to each floor beam. The center strake of the bottom plating is $\frac{3}{8}$ in. thick, the other strakes being $\frac{5}{16}$ in. thick. The deck plating is ¼ in. thick. The upper strake of the side plating is $\frac{3}{8}$ in. thick, and the other side plates are $\frac{5}{16}$ in. thick. The hull is divided into 11 water-tight compartments.

Each dredge is provided with two centrifugal pumps with a single suction in the axis of the pump discharging from the lower side of the casing. The suction is 20 ins. in diameter and the discharge at the

pump is the same diameter, but is expanded to 24 ins. at the discharge pipe. The casing of the pump is 48 ins. in diameter and 28 ins. across the inside. It is provided with liners which can be renewed when worn. The pump runner is 48 ins. in diameter and is provided with three reversed-curve arms. The ends of these arms are fitted with detachable extension plates made of mild steel. An adjustable thrust bearing is provided. A water-jet is connected with the main bearing to keep out the sand and grit when the pump is running.

Each pump is operated by a direct-connected, horizontal, compound, non-condensing engine. These engines are designed to run 200 revolutions per minute and develop 300 H.-P. at a boiler pressure of 140 lbs. This speed is to be regarded as the average work of the engine, and is expected to maintain through the suction and discharge pipes the velocity necessary to carry at least 20% of sand and 80% of water under a maximum head of 30 ft.

A jet pump is provided with each main pump which serves to loosen up the material at the end of the suction and thus facilitate its passage into the suction pipe. The jet pump has two high-pressure cylinders 8 ins. in diameter, two low-pressure cylinders 12 ins. in diameter, and two water plungers 12 ins. in diameter; all having 10-in. stroke. The capacity of the pump is 1 200 galls. per minute against a water pressure of 65 lbs. when running compound under a steam pressure of 150 lbs. These pumps discharge through 8-in. pipes terminating in three bronze nozzles 1½ ins. in diameter, their extremities radiating to a distance of about 30 ins. apart and just beneath the suction of the main pump.

Steam is supplied by six boilers of the Mississippi River steamboat type. These boilers are 48 ins. in diameter and 28 ft. long, and each shell contains five 11-in. flues. They are made of marine steel of 60 000 lbs. tensile strength, and in all respects conform to the rules of the Board of Supervising Inspectors. They are designed for a working pressure of 140 lbs. per square inch. The boilers are arranged in two batteries, with three boilers in each, which are connected by one 30-in. steam drum and two 15-in. mud drums. The steam connections are so arranged that one or both batteries can be used at will. There are two smokestacks 42 ins. in diameter and 70 ft. high. The boilers are supplied by two feed pumps with outside-packed plungers 4½ ins. in diameter and 10-in. stroke.

DREDGE DELTA
BOULDERS and OTHER STUFF
TAKEN UP BY CUTTERS AT PRES-
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FIG. 1.

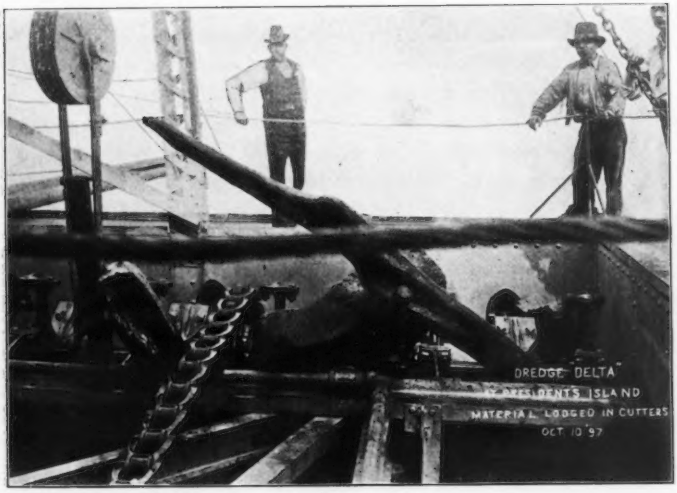

DREDGE DELTA
PRESIDENTS ISLAND
MATERIAL LODGED IN CUTTERS
OCT. 10 '97

FIG. 2.

The boilers and machinery rest on I-beam keelsons, the hull being left open for the space occupied by these parts. The remainder of the hull is decked over with steel plates. A vertical anchor spud is placed near the bow of the hull.

The main suction pipes are suspended from a derrick frame and are raised or lowered as required by winches, so that each suction can be operated independently. The suction head opening, or end of the suction pipe, is 20 ins. high by 120 ins. long. The inner end of the suction works on a hinge and slip joint.

There is one 24-in. tank-steel discharge pipe for each pump. Each of these pipes is attached to the fixed sections in the hull by a horizontal swivel joint which admits of swinging the pipe out sidewise. The pipes are in lengths of 24 ft., and each length is floated on a steel pontoon with pointed ends, the pipe being attached to the float at the middle joint in such a way that the pontoons lie parallel with the current when the pipes are deflected to one side. Each discharge pipe is 500 ft. long, the several joints being connected together with rubber gaskets. The first joint is connected to the fixed joint at the stern of the dredge by a heavy rubber coupling 3 ft. 8 ins. long.

In operating the dredge, two iron piles are set on line with the cut, and the dredge is attached to them by two ¾-in. wire cables 1 200 ft. long. The dredge end of each of these cables is attached to a winch having a 42-in. drum. These winches have double engines and are geared so as to give speeds from ¼ in. to 7 ins. per second. The dredge is pulled ahead as rapidly as the dredged material can be taken through the pipes, which, of course, varies with the depth of material handled.

The electric light plant consists of one 4 000 candle-power search light, two 2 000-candle-power arc lights, and seventy-five 16-candle-power incandescent lights. The dynamo is a 110-volt machine of the Western Electric pattern, operated by a horizontal, single expansion 7 x 10-in. engine.

A cabin provides ample quarters for officers and crew, and a machine shop gives facilities for repairs.

Dredge Ram.

In the fall of 1893 the dredge *Ram* was completed by the Bucyrus Steam Shovel and Dredge Company, for use in keeping open the channel from the Mississippi River into the Red and Atchafalaya Rivers.

It was built under the direction of Captain John Millis, Corps of Engineers, U. S. A. This dredge cost $69 500. The capacity is about 300 cu. yds. of mud per hour, delivered through 300 ft. of pipe. It is provided with propelling machinery such as commonly used on stern-wheel steamboats. The hull is 95 ft. long, 27 ft. beam and 7½ ft. deep. It is built of long-leaf yellow pine. It has two longitudinal and two transverse bulkheads, dividing the hull into nine water-tight compartments. The dredging pump is an Edwards centrifugal, with 15-in. suction and discharge. The intake is from the starboard side and the discharge from the bottom of the casing. The pump is run through a belt connection by a horizontal, compound-condensing engine. The cylinders are 14½ and 26 ins. in diameter, with a stroke of 20 ins.

This dredge can work in any depth up to 30 ft. It is so arranged that material can be discharged on either side at will. A vertical anchor spud is provided in the stern of the boat, on which it swings by means of kedge anchors laid out from either side of the bow and maneuvered by winding drums. In this way a wide cut can be made by swinging the cutters from side to side.

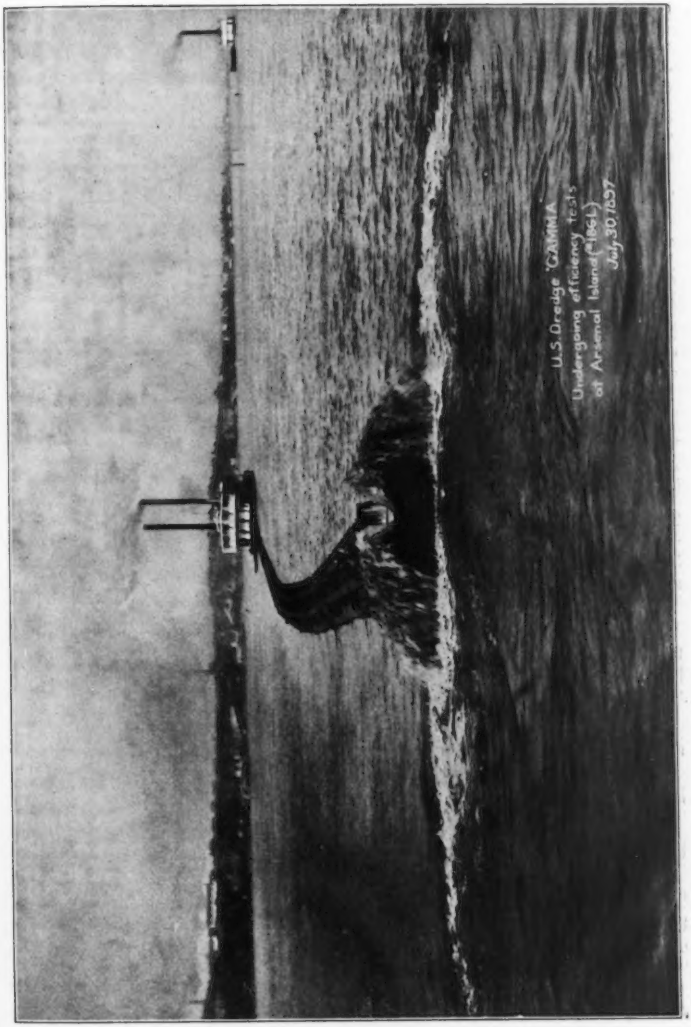
The cutter and suction is supported by an A-frame, the inner legs of which are pivoted to the sides of the bow. The frame is raised or lowered with wire rope tackle attached at the upper end to suitable shears and operated by winding drums. The cutter is a conical steel casting with eight steel blades forming a cutter 24 ins. in diameter at the end and 54 ins. in diameter at the base. This cutter is at the outer extremity of a 5-in. steel shaft, which is revolved by gear wheels at the bow of the boat, and operated by a sprocket wheel and chain. The suction proper starts at the base of the cutter.

The propelling engines have 15-in. cylinders and a 52-in. stroke. There is a combined, duplex air and feed pump and condenser, with 7½-in. steam cylinder, 7-in. air cylinder and 10-in. stroke. Fire and bilge pumps are also provided.

The cutter shaft and winding drums are operated by a pair of auxiliary engines, the cylinders of which are 9 ins. in diameter and 12-in. stroke. The drums are worked by separate clutches.

Steam is supplied by two main boilers 16 ft. long and 60 ins. in diameter. Each shell has 74 3-in. tubes and a corrugated furnace flue 40 ins. in diameter and 72 ins. long.

PLATE XXXV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 838.
OCKERSON ON DREDGES AND DREDGING.



The boat is lighted throughout by electricity. There is a double-deck cabin which provides ample accommodations for the crew and protects the machinery.

This boat has been quite successful from the start. During the low-water season of 1894 she dredged 265 000 cu. yds. of material at a cost of a trifle over 4½ cents per yard. The material was largely mud and clay. The material is generally delivered through about 50 ft. of pipe suspended from a derrick and attached to the boat, as shown in Plate XXXIII, from which a good general idea of this boat can be obtained.

It has also been used with considerable success in building levees. It is estimated that under favorable conditions a levee 10 ft. high can be built at a cost of about 6 cents per cubic yard.

Menge Dredges.

In 1888 two dredges of the elevator type were procured, one for use in Vicksburg harbor and one for the mouth of the Red River. These were called the *Menge* and the *Pah-Ute*.

In actual work the *Menge* has dredged 4 000 cu. yds. in 10 working hours. This dredge cost about $18 000. The *Pah-Ute* has about half the above capacity and cost $10 000. These dredges, as generally equipped, deliver the dredged material into dump scows which are towed to the desired point and dumped. In some favorable situations the material is delivered through sluice boxes supported on barges. These dredges, if properly constructed, are very successful when operated in soft material.

At the mouth of the Red River the efficiency of propeller wheels and stern-wheel boats has been thoroughly tried in removing the sediment and keeping the channel open. Under favorable conditions some good results have been obtained in this way; but on the whole, it is generally conceded to be a very poor makeshift.

Dredge *Bayley*.

The dredge *G. W. R. Bayley* was built by Carroll & Company, of Pittsburg, for use in South Pass. It arrived at Port Eads in the fall of 1877. This boat is constructed of iron throughout. The hull is about 200 ft. long over all, 32 ft. wide, and 10 ft. depth of hold. With fuel on board, it draws about 5 ft. of water. It is self-propelling

by means of side wheels 25 ft. in diameter, with buckets 11 ft. long. These wheels are operated by two engines with 21-in. cylinders and 7-ft. stroke. The boat is provided with a rudder at each end to obviate the necessity of turning when dumping or returning to the cut.

This dredge has a centrifugal pump of the Andrews Cataract pattern, with a runner 6 ft. in diameter and 3 ft. wide, mounted on an 8-in. steel shaft. It is operated by two independent condensing engines, placed forward of the pump, having 24-in. cylinders and 20-in. stroke. The wrought-iron suction pipe is 27 ins. in diameter. This suction operates in a recess 4 ft. wide, and 25 ft. in length, located at the stern of the boat. It connects with the pipe in the boat, just above the bottom plating and near the pump, by means of a joint which admits of a deflection of 30° from the axis in any direction. The lower end of the suction is curved and flattened out to a width of 4 ft., and is armed with a steel scraper. The suction is supported on a flat plate resting on the sand to prevent the scraper from cutting too deep. This scraper takes in a slice of sand about 8 ins. deep and 4 ft. wide. A stream of water of about half the above depth and the same width enters the suction at the same time.

The movable part of the suction, when in operation in 26 ft. of water, stands at an angle of about 35 degrees. When not in use it is lifted above water, under the extension of the main deck, the end projecting about 15 ft. aft of the stern post. The discharge pipe is 30 ins. in diameter and is arranged so that the spoil can be deposited in the spoil bins on board, or delivered on either side of the boat through pipes swung from derricks. There are four boilers, 42 ins. in diameter and 26 ft. long, with four flues in each.

The four spoil bins stand forward of the engines. They are 60 ft. long, 19 ft. wide and about 20 ft. deep, and have a capacity of about 512 cu. yds. of dredged material. These tanks are filled in about 7 minutes, when the suction is raised and the boat proceeds to the dumping ground. Two-thirds of the available time is occupied in unloading. Overflow gates are provided so as to allow the water to escape while the sand settles to the bottom, thus insuring a greater load of solid matter. In a working day of 13 hours the average amount of solid matter removed is 1 309 cu. yds. The tanks are divided into compartments, each of which terminates in a hopper having a 4-ft. opening through the bottom of the hull. These openings are

LOWER POINT PLEASANT BAR

79.5 MILES BELOW CAIRO

SCALE OF FEET

1000 0 1 2 3000

ALL DEPTHS REFER TO THE LOWEST STAGE OF 1896.

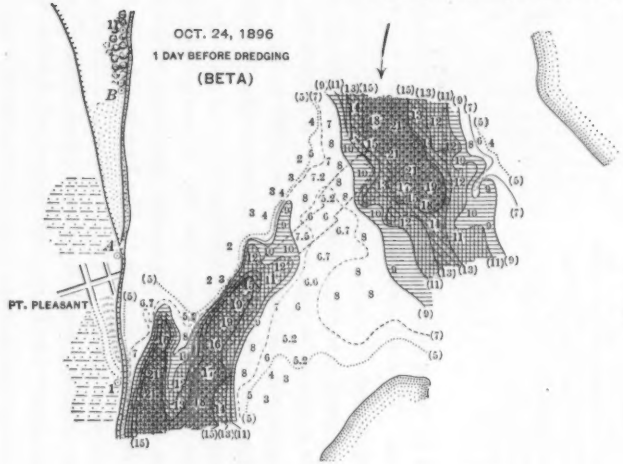


FIG. 13.

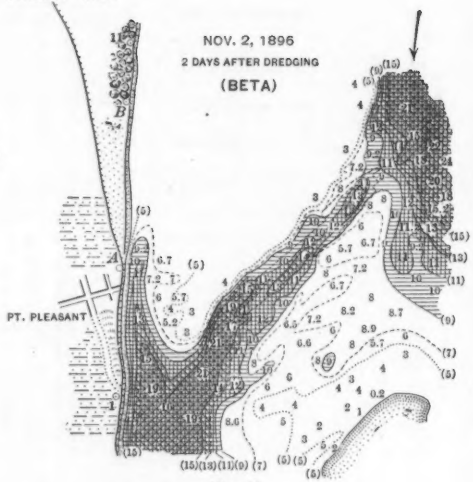


FIG. 14.

TABLE No. 10.—Summary of Dredging Operations, Mississippi

OF

Place and date.	Name of dredge.	Cuts.				Average depth in feet.			
		Number.	Total length. Feet.	Time required. Hours.	Rate, ft. per hour.	Suction.	Ahead of dredge.	Astern of dredge.	Material removed.
Island No. 40 (211 L), August 31st to September 24th, 1896....	*Beta.*	10	5 945	121.0	49.1	15.3	9.2	13.4	4.2
Island No. 34 (179 R), September 25th to 30th, 1896.....	*Beta.*	3	2 265	66.0	34 3	15.6	9.5	13.5	4.0
Osceola Bar (164.5 R), September 30th to October 9th, 1896....	*Beta.*	9	5 660	63.7	89.0	15.0	9.4	13.5	4.1
Hathaways Lower Crossing (102 L), October 9th to 15th, 1896	*Beta.*	16	12 175	87.0	140.0	20.5	14.8	18.7	3.8
Cherokee Crossing (89 R), second time, October 15th to 24th, 1896.....	*Beta.*	11	6 435	78.2	82.3	17.0	10.8	15.8	5.0
Lower Point Pleasant, Mo. (79.5 R), October 25th to November 3d, 1896	*Beta.*	13	9 415	109.2	86.2	16.0	7.7	13.5	5.8
Cherokee Crossing (89 R), third time, November 4th to 13th, 1896.....	*Beta.*	10	8 980	175.0	51.3	17.3	10.7	16.1	5.4
Cherokee Crossing (89 R), first time, September 5th to 28th, 1896.....	*Alpha.*	6	4 610	294.0	15.7	12.0	7.8	10.9	3.0
Upper Point Pleasant, Mo. (79 R), September 29th to October 23d, 1896....	*Alpha*	4	6 370	306.7	20.8	13.0	9.3	11.7	2.4
Compromise Bar (77 L). October 24th to November 15th, 1896....	*Alpha.*	7	5 405	257.7	21.0	12.7	9.9	11.6	1.7

closed by valves operated by hydraulic jacks with a capacity of about 12½ tons. The sand is washed out of the tanks by means of two jets in each hopper.

The capacity of the dredge when delivering the material as described is about 350 cu. yds. per hour. If the material is simply delivered overboard, the capacity is about 1 000 cu. yds. per hour. When dredging, the boat moves down stream, with the suction lowered, at the rate of about 2½ miles per hour.

This dredge cost about $150 000. It was designed by Jas. B. Eads, M. Am. Soc. C. E., for the special purpose of working in deep rough water with strong currents. * This boat is now over twenty years old, but is still serviceable.

The foregoing descriptions cover a fleet of eight hydraulic dredges of large capacity and five other dredges, all of which are now available

* See "The Mississippi Jetties," by E. L. Corthell, M. Am. Soc. C. E.

RIVER BETWEEN CAIRO AND MEMPHIS. DURING LOW-WATER SEASON 1896.

Heads in feet.		Revolutions. Ave. per min.		Steam pressure.	Distribution of time by hours.									Total cost.
Suction.	Delivery.	Pumps.	Cutters.		Placing plant.	Dredging.	Changing cuts.	Repairs.	Passing boats.	Making up tow.	Towing.	Sundays and holidays.	Total time.	
14.4	19.1	129	15	161	53.5	121.0	25.2	12.7	1.0	39.0	104.0	19.0	375.5	$6 122.51*
15.2	21.6	134	16	165	16.5	66.0	5.0	14.5	.....	6.5	25.5	.....	134.0	1 793.42
15.2	20.8	135	15	167	11.0	63.7	7.7	6.5	.....	20.5	97.5	10.0	217.0	2 379.05
15.0	23.4	134	16	160	23.0	87.0	.....	.....	.....	5.5	28.0	.....	143.5	1 671.59
14.5	24.5	135	16	163	9.5	78.2	.....	9.7	.....	18.0	24.0	.....	139.5	1 742.58
15.2	25.6	136	16	162	13.0	109.2	.....	62.7	.....	7.0	24.0	24.0	240.0	2 315.51
13.6	25.9	137	14	164	14.0	175.0	.....	24.0	.....	24.0	.....	3.0	240.0	3 008.93
5.2	16.8	124	Water-jet.	138	32.0	294.0	11.0	143.0	.....	24.0	8.0	64.0	576.0	3 309.51†
6.3	19.5	118		141	14.2	306.7	15.7	79.2	.....	.....	9.0	70.0	495.0	3 456.16†
5.8	20.4	120		139	13.5	257.7	8.25	93.0	.....	37.5	10.5	59.5	480.0	3 473.68†

* Capsizing of pipes delayed the work 22½ hours.

† 114¾ hours. } Repairs due to breaking of runner of main pump.
78 hours. }
91 hours. }

for use in improving the low-water navigation of the Mississippi River. The dredge *Alpha* has been operated for three seasons, the *Beta* for two seasons, and the *Gamma* and *Delta* for one season. They have all demonstrated the practicability of moving economically immense quantities of material in a short space of time. They have also shown that good navigable channels can be opened through the reefs that obstruct navigation.

As far as the machines themselves are concerned, they seem to meet the requirements fully. The value of these dredges as aids to navigation depends far more on the proper location and direction of the cuts to be made than on the efficiency of the machinery. Experience may show that in some cases the dredges can be made more efficient by filling side chutes and thus throwing the water into

one channel, rather than attempting to enlarge one of the channels by dredging out the material. It may also be found desirable in some cases to discharge the material at the sides of the proposed channel rather than to deliver it at a distance through long discharge pipes.

As has already been stated, the volume of material rolled along the bottom is so great as to far outweigh the greatest possible capacity of any dredge. To those who are not familiar with this phenomenon it will seem incredible that a dredge with a capacity of over 1 000 cu. yds. per hour may be operated for days and leave scarcely a trace of the cut. Or, on the other hand, if the cut has been so located as to meet the requirements of the current, a channel will be scoured out and an amount of material removed which would probably exceed the capacity of the dredge many times. It is by no means certain that the channel will always follow the line of the cuts. It sometimes happens that after some days of diligent dredging, a channel develops without assistance on a line quite remote from the dredged cuts.

Whatever is done during one low-water season is generally obliterated by the succeeding high water. The successful location of a cut during one low-water season does not necessarily imply that a similar location during the following season will give like results. In fact, a new problem is presented by each bar every season.

In a stream of this character it is, of course, extremely difficult to determine in a particular case just what share of the channel should be credited to the dredging and what proportion to natural causes. Enough bars have been dredged, however, to fully demonstrate that the dredging at least induces the scour which eventually results in a wide and deep channel.

During the low-water season of 1896 there were eight bars between Cairo and Memphis which obstructed navigation. Channels were successfully opened through all of them except one, which was abandoned on account of an extraordinary change in the river which shifted the channel from the right to the left bank. One of the most interesting of these bars is shown in Figs. 13, 14, 15 and 16. Fig. 13 shows that one day before dredging there was barely a 7-ft. channel between the upper and lower pools. The broken lines enclose the area where the dredging was done. The controlling depth in this area was 6 ft.

LOWER POINT PLEASANT BAR

79.5 MILES BELOW CAIRO

SCALE OF FEET

1000 0 1 2 3000

ALL DEPTHS REFER TO THE LOWEST STAGE OF 1896.

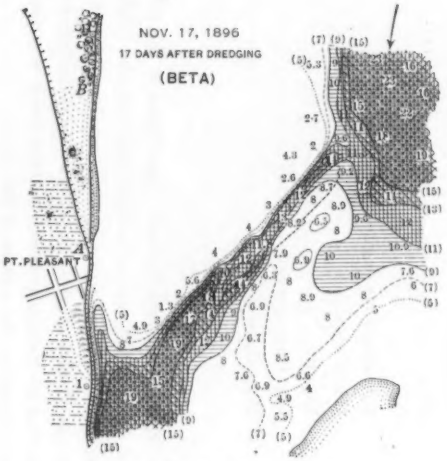


FIG. 15.

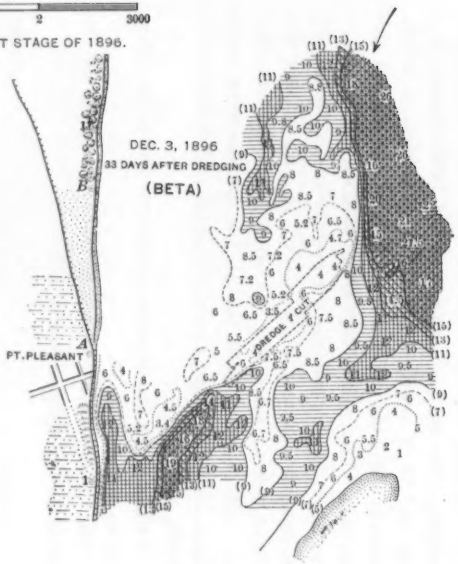


FIG. 16.

Fig. 14, two days after dredging was completed, shows the two pools connected by a good 9-ft. channel with 11 ft. of water for the greater part of the length. Fig. 15 shows the conditions seventeen days after dredging. The cut has deepened and an 11-ft. channel from pool to pool, and 13 ft. nearly all of the way through, is found. Fig. 16 shows, in a forcible way, the magnitude of the natural movement of sand bars. Thirty-three days after dredging, the channel was found to be about 500 ft. below the cut opened by the dredge. The site of the dredged channel, which in Fig. 15, only sixteen days earlier, showed 13 ft. of water, now has barely 4 ft. The 9-ft. channel, however, still remains, although it has drifted down stream. This change occurred during a rapid rise at the end of the low-water season of 1896.

A summary of the dredging operations during the season of 1896 is given in Table No. 10.

The following table shows the cost of operating the two dredges during the low-water season of 1896:

Labor	$16 237.06
Subsistence	3 386.67
Fuel	8 051.73
Oil	242.39
Miscellaneous engineers' supplies	176.43
Mates' supplies	94.73
Repairs	855.41
Lighting supplies	114.58
Miscellaneous	113.94
Total	$29 272.94

This only covers the cost of operation at the several bars, and does not include the cost of repairs prior to the beginning of work, the expenses incurred while waiting developments in the stage of river to see whether further work was necessary or not, nor the cost of moving to winter quarters. These items amount to $12 953.23, giving a total for the season of $42 226.17.

During the low-water season of 1897 four dredges were at work on the bars below Cairo. The cost of operating them is given in the table on page 306.

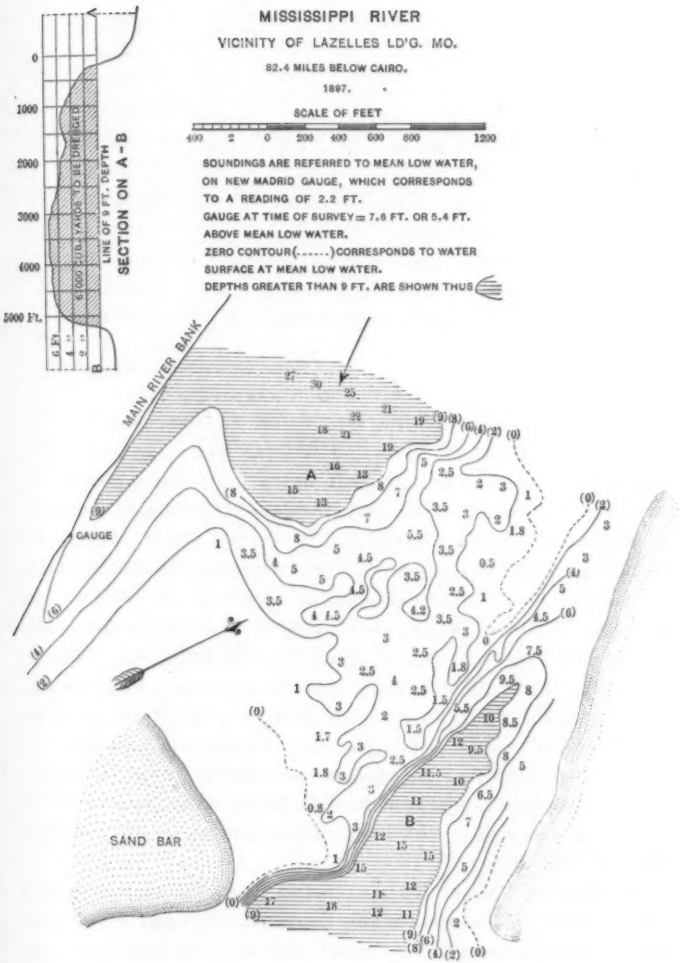

MISSISSIPPI RIVER
VICINITY OF LAZELLES LD'G. MO.
82.4 MILES BELOW CAIRO.
1897.
SCALE OF FEET
400 200 0 200 400 600 800 1200
SOUNDINGS ARE REFERRED TO MEAN LOW WATER, ON NEW MADRID GAUGE, WHICH CORRESPONDS TO A READING OF 2.2 FT.
GAUGE AT TIME OF SURVEY = 7.6 FT. OR 5.4 FT. ABOVE MEAN LOW WATER.
ZERO CONTOUR(.....)CORRESPONDS TO WATER SURFACE AT MEAN LOW WATER.
DEPTHS GREATER THAN 9 FT. ARE SHOWN THUS
SECTION ON A-B
LINE OF 9 FT. DEPTH
6000 CUBIC YARDS TO BE REMOVED
0
1000
2000
3000
4000
5000 Ft.
MAIN RIVER BANK
GAUGE
SAND BAR
A
B

FIG. 17.

COST OF OPERATING DREDGES DURING LOW-WATER SEASON OF 1897.

Labor	$26 704.53
Fuel	13 474.23
Subsistence	7 586.99
Lubricants	970.79
Lighting supplies	215.05
Miscellaneous supplies	1 527.79
Office supplies	145.10
Hire of tow boats for moving plant	10 115.50
Preparation and moving into field	3 269.44
Moving to winter quarters at end of season	4 637.03
Cost of inspection and supply boat	10 554.75
Cost of operating two survey boats	8 674.10
Total	$87 875.30

Fig. 17 shows a conspicuous sand bar at Lazelles, some 82 miles below Cairo. When the survey of this bar was made, just before dredging, the distance from the 9-ft. depth in the upper pool to the same depth in the lower pool was 1 400 ft. At that time the amount of excavation required to make a 9-ft. channel 250 ft. wide at the datum stage was 61 000 cu. yds. The dredge *Gamma* was at work on this bar ten days, and the actual dredging time was one hundred and seventy-eight hours. Taking the capacity of the dredge as 800 cu. yds. per hour gives the total amount dredged as 142 400 cu. yds. Thirty-one days after the dredging was completed there was a 10-ft. channel clear through the reef, except for a distance of about 225 ft. where the depth was only 8 ft. (see Fig. 18). Seventy-six days after the dredging was completed the channel was found to be 350 ft. wide at the narrowest point, over 1 000 ft. wide for more than nine-tenths of the length, and with a least depth of 9 ft., and an average depth of 11 ft. (see Fig. 19).

At Hathaways, about 104 miles below Cairo, the surveys showed a very ragged 7-ft. channel before dredging. One and a half days after dredging, a narrow 9-ft. channel connected the upper and lower pools, and a clear 8-ft. channel 350 ft. wide extended across the bar. Thirty days later the channel was found to be 12 ft. deep and 800 ft. wide with the exception of a narrow shoal at the lower end.

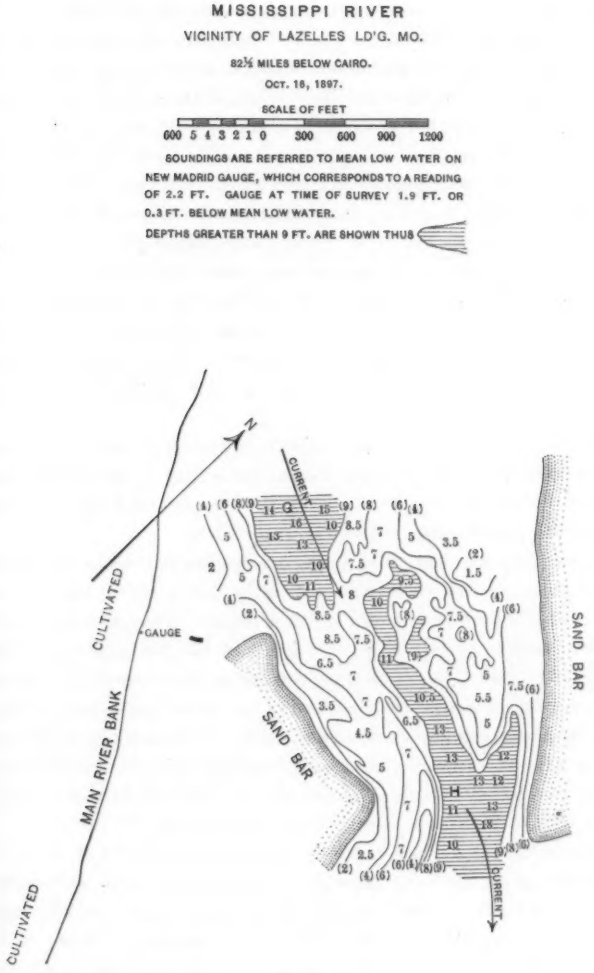

MISSISSIPPI RIVER
VICINITY OF LAZELLES LD'G. MO.
82½ MILES BELOW CAIRO.
OCT. 16, 1897.
SCALE OF FEET
600 5 4 3 2 1 0 300 600 900 1200
SOUNDINGS ARE REFERRED TO MEAN LOW WATER ON NEW MADRID GAUGE, WHICH CORRESPONDS TO A READING OF 2.2 FT. GAUGE AT TIME OF SURVEY 1.9 FT. OR 0.3 FT. BELOW MEAN LOW WATER.
DEPTHS GREATER THAN 9 FT. ARE SHOWN THUS
N
CURRENT
CULTIVATED
GAUGE
MAIN RIVER BANK
SAND BAR
SAND BAR
CULTIVATED
CURRENT
G
H

FIG. 18.

At Beef Island, 211 miles below Cairo, the channel was deepened 2 ft. in one hundred and six hours of actual dredging by the dredge *Delta*, in spite of the presence of many sunken logs and snags.

At President's Island, just below Memphis, the dredge *Delta* was employed in opening a channel through a reef which was causing much trouble to navigation. In the bed of the river in this locality there is a considerable quantity of conglomerate rock and lignite to be found. The mechanical agitators of the *Delta* were therefore put to a very severe test. One solid piece $3\frac{1}{2}$ x $4\frac{1}{2}$ ft. was caught in the cutters (see Figs. 1 and 2, Plate XXIV). It had to be broken into small pieces to dispose of it. When work began there was barely a 5-ft. navigable channel across this bar. After fifteen days' work, during which period much time was lost in clearing the cutters of debris, leaving only eighty hours' actual dredging time, a 9-ft. channel 100 ft. wide and 1 300 ft. long was completed. This channel remained intact throughout the season, although a wider channel broke through the bar lower down.

During the low-water season of 1897 channels were dredged through fifteen bars lying between Cairo and Graves Bayou, 248 miles below. A view of a dredge at work, showing the pipe line and the discharge against the baffle plate, is shown in Plate XXXV.

There were bars that obstructed navigation below Graves Bayou, as far down as Arkansas City, 435 miles below Cairo, and one bar even below Natchez, 710 miles below Cairo. The dredging plant, however, was too small to cover more than the 250 miles from Cairo southward. The total number of obstructing bars below Cairo during the low-water season of 1897, where the navigable depth was less than 8 ft., probably did not exceed twenty-five. Estimating each of these bars at 2 000 ft. in length, the result is an aggregate of about $9\frac{1}{2}$ miles of bad navigation in a total length of 1 060 miles of river from Cairo to the Gulf of Mexico, or less than 1% of the length.

Estimating the average depth of cut required as 4 ft. and the width at 250 ft., gives the total amount of material to move as 1 852 000 cu. yds. To remove this amount in ten days would require eight dredges running the full time without interruption. Table No. 8 shows that only about half of the time is utilized in actual dredging.

These bars do not all develop at the same time, and they do not necessarily develop at the same places during successive seasons.

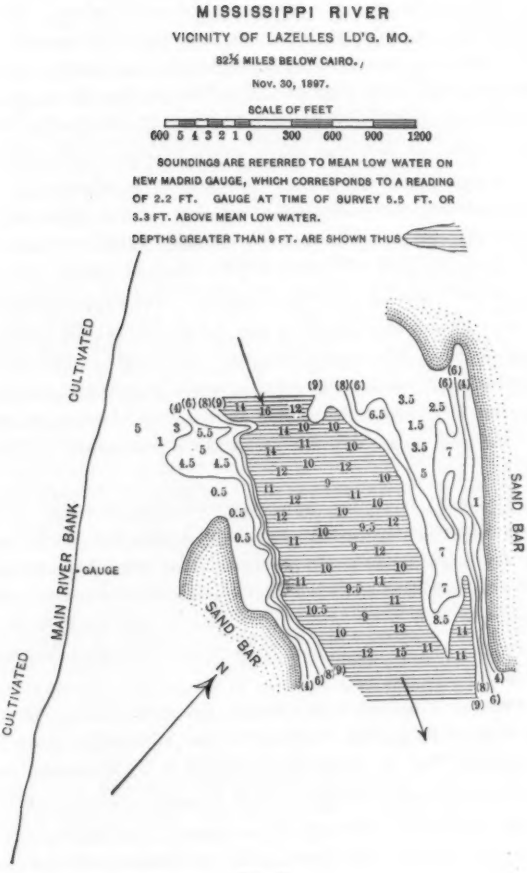

MISSISSIPPI RIVER
VICINITY OF LAZELLES LD'G. MO.
82½ MILES BELOW CAIRO.,
Nov. 30, 1897.
SCALE OF FEET
600 5 4 3 2 1 0 300 600 900 1200
SOUNDINGS ARE REFERRED TO MEAN LOW WATER ON NEW MADRID GAUGE, WHICH CORRESPONDS TO A READING OF 2.2 FT. GAUGE AT TIME OF SURVEY 5.5 FT. OR 3.3 FT. ABOVE MEAN LOW WATER.
DEPTHS GREATER THAN 9 FT. ARE SHOWN THUS
CULTIVATED
MAIN RIVER BANK
GAUGE
CULTIVATED
SAND BAR
SAND BAR
N

FIG. 19.

There are, however, certain general localities that have long been recognized by steamboatmen as liable to develop bad navigation during any low-water season. Now and then, even these places pass through a season without developing any serious obstructions, and at such times dredging below Cairo will be unnecessary. Seasons having good navigation throughout are, however, not frequent.

Dredging operations will, in the main, be confined to the same general localities from year to year, although wrecks, snags and bank erosions may occasionally develop new bars that will require dredging.

The season of 1895 was one of extraordinarily low water. At one time during that season there were thirty-seven crossings between St. Louis and Cairo, where the water was 6 ft. or less in depth. During ordinary seasons about as much dredging would be required between St. Louis and Cairo to secure a 9-ft. channel 250 ft. wide as is required below Cairo for a similar channel. The supply of water above Cairo at extreme low stages is too limited to readily admit of 9-ft. channel depths. The requirements of river traffic on this reach would be satisfied fairly well by 7 or 8 ft., and it is doubtful whether these depths can be materially exceeded by means of dredges or other temporary devices at an expense justified by the value of the results obtained.

It is evident from the foregoing that the problem of keeping navigation open in the Mississippi River during the low-water season is very far from being a simple one. The magnitude of the plant described is sufficient evidence that strenuous efforts are being made to "improve and give safety and ease to the navigation" of the river, and the experience gained thus far justifies the belief that these efforts will be successful.

The writer is indebted to General John M. Wilson, M. Am. Soc. C. E., Chief of Engineers, U. S. A.; to the Mississippi River Commission, to Major Thos. H. Handbury, Captain H. E. Waterman and other officers of the Engineer Corps, for free access to records and drawings. He is also indebted to his associates, engaged in the improvement of the river, for valuable assistance in the preparation of drawings and tabulated data.

DISCUSSION.

B. L. Crosby, M. Am. Soc. C. E.—The speaker has had a great deal of serious trouble with deposits caused by anchoring barges in the current, and although his experience has been on the Missouri rather more than on the Mississippi, yet the lower Missouri may be considered as virtually the same river. Mr. Crosby.

The author states that it is a well-known fact that a barge anchored in shallow water will very soon cause the sediment to deposit, but does not say that it will be formed under the barge—it is always formed immediately down stream from it. In the speaker's opinion, that would be the result with any deflector—that the point of trouble would be simply transferred to a point a little further down stream.

When a long barge is anchored in shallow water, the material scoured out at the bow is sometimes deposited at its stern, so that the barge is aground at the stern and in deep water at the bow.

Edward Flad, M. Am. Soc. C. E.—The speaker agrees entirely with the conclusion reached by Major Harrod, that the water-jet agitator is a more efficient and a better machine than the mechanical agitator, for the conditions under which the dredges *Epsilon* and *Zeta* are ordinarily required to operate. Referring to the tests of these dredges, the author states that it was demonstrated therein that the capacity of the pump with the mechanical agitator was not much over half the capacity of the pump with the jet agitator. The speaker disputes that statement. He was present during all the tests of these two dredges, and acted as engineer for the contractor during the period of the detail designing and testing of both dredges. At first sight, judging from the report of the tests, the author's conclusions might seem warranted, but, taking into consideration the conditions under which these tests were made, his conclusions are entirely wrong. The two dredges were turned over to the Government at the same time to be tested, and the *Epsilon*, which was provided with the water-jet agitator, was tested first; the result being 757 cu. yds. of sand per hour. The contract requirement was 1 000 cu. yds. of sand per hour, and the contractor was much disappointed at the result of the first test, because he had anticipated that the dredge would pump 2 000 or 3 000, or, perhaps, 4 000 cu. yds. per hour. A second test was made and showed 714 cu. yds. of sand per hour, which was likewise unsatisfactory. Mr. Flad.

The tests were made by attaching to the end of the dredge a barge, into which the material was pumped; then the water was withdrawn and the sand was measured. It was observed that the sand which was being pumped was very fine and contained a large number of mud lumps. It was therefore concluded that this was the cause of the reduced capacity, and, as the contract provided that the test should

Mr. Flad. be made under average conditions and with average river sand, it was very properly decided that the dredge should be moved to some other location. Another part of the district, near New Madrid, was chosen, where a very good average river sand was obtained.

All these tests were made under conditions which were calculated to develop the highest capacity of the dredges. Everything was run at the highest speed. The dredges were pulled ahead on wire cables with as great a speed as possible.

The first test in the new location showed 1 712 cu. yds. per hour, and the next 2 800 cu. yds.; the next 3 100 cu. yds. Five tests in all were made on this good material. In determining the average capacity of this dredge the first two tests were, of course, properly omitted, because the material was not what the contract called for. The average of the last five tests was 2 500 cu. yds. per hour, which was very satisfactory.

After these tests on the *Epsilon* were finished, those on the *Zeta* were commenced. During this time the water had been rising, and it was necessary to move the *Zeta* into what is called a high-water sand bar, which is largely filled with drift, logs and lignite, and is a very hard material for any dredge to handle—and especially severe for a dredge provided with a mechanical agitator. However, as the contractor was anxious to complete his test and get his money, he agreed as to the location—the only one available at that time. The first test showed 1 878 cu. yds. per hour, which was thought to be a fairly good showing, the contract requirement being 1 000 cu. yds. The next test showed only 1 300 cu. yds. It was soon found that the dredge was working in a bed of brush and logs, and there was a great deal of difficulty in going ahead. Forcing the dredge to any excessive or even reasonable speed, resulted in breaking the shearing pin of the agitator. However, these tests were sufficiently satisfactory to the contractor, because they were in excess of his contract requirements, and he raised no serious objection to them. The average result of the five tests was 1 364 cu. yds. per hour.

In order to enable one to compare the relative value of the two machines the tests should have been made under the same or similar conditions. Now, as the tests of the *Epsilon*, with the water-jet, were made under very favorable conditions for a high-capacity test, and those of the *Zeta* were made under perhaps the most unfavorable conditions, it was entirely improper to compare the relative capacity on those tests. The speaker believes that the author does not realize the conditions under which the tests were made, because he was not there at the time.

He further states, in reference to the mechanical agitator, "It will therefore be taken out, and jets will be put in." He is mistaken in that statement. The government officer in immediate charge decided that

he would like to remove the mechanical agitator, and his views were presented to the local members of the Commission at St. Louis. They considered the question, and came to the conclusion that, in place of removing the mechanical agitator, they would install, in addition thereto, the water-jet agitator, which was the plan originally contemplated in the construction of the dredges. In fact, the mechanical agitator was so designed that the water-jet agitator could be used in conjunction with it or as a substitute for it, and at the time the dredges were being constructed it was urged upon the Commission that they install the jet agitator in addition to the mechanical agitator. Mr. Flad.

CORRESPONDENCE.

Mr. Harrod. B. M. HARROD, Past-President, Am. Soc. C. E.—This paper is of much interest as a full and accurate description of a new and important development of engineering work.

The method of dredging now in use on the alluvial parts of the Mississippi River has arisen from the inadequacy, when applied there, of methods which have been more or less successful on streams of different character and of smaller dimensions.

The great specific gravity of the material of the bars, which is mostly a clean silica sand, and the distance it would have to travel in suspension before reaching a pool in which it could settle down harmlessly, make any method which proposes merely stirring up the sand, and trusting to the current to remove it, quite ineffective.

The successful results which have been obtained with spurs and dikes in improving the navigation of smaller streams are both doubtful and costly on a river with the characteristics and dimensions of the Mississippi. The bars naturally form in the wider reaches, at the node, or reversion point, between two bends. The banks at such places are frequently a mile or more apart, and the bar, with a 5-ft. crest, has a width, between the contours, of satisfactory depth for navigation (8 to 10 ft.), which must be connected through the intervening shoaler water of a third or half a mile.

While the bars reappear annually in about the same neighborhoods, the changes of location are sufficient to render resurveys necessary each year at the approach of low water; and since the bars and the natural channels through them—generally the latter—may shift up or down during the season, these surveys must be continued until the autumnal rise brings relief.

The same bars, or groups of bars, do not, from year to year, present the same relative degree of obstruction to navigation. A bar which in one year limits the navigable depth of the river to 5 ft., may, in the next, have 8 or 10 ft. over it, and the trouble be transferred to a neighboring locality which, in the previous year, presented few or no obstructions.

The drop during the falling stages is apt to be rapid, and in a week's time the entire barge and through commerce of the river may be arrested. The improvement of the bars should, therefore, begin within the least possible time after the river has reached a stage that will allow the making of surveys necessary for the location of the work, and the work should be of a character that will admit of very rapid application, extension and results.

If it is attempted to meet these difficult conditions with spurs or dike work, it is quite evident that preparation must be made, at each

bar, for building several dikes, each of which may require to be of great length; that similar preparations must be made at many bars; that the character of these works must be temporary or portable; and that such preparations involve the providing of an immense plant of tow-boats, barges and pile-drivers, and a very large force, in order to supply material and erect extensive structures, at many places, and within a very short time. All this is absolutely necessary for a satisfactory low-water improvement of the Mississippi by spur or dike work; and even then, from the shifting character of the bed and banks of the Great River, it does not promise to be more permanent than dredging. Mr. Harrod.

On the other hand, it is quite practicable, and the writer believes it will be found less expensive and more reliable, to have a fleet of such a number of dredges that one could be in waiting, during the falling stages of the river, at each bar where there might be reason to apprehend trouble, ready to go to work, if necessary, whenever a depth of not more than 12 ft. or 15 ft. was found.

During the progress of this work several interesting problems have arisen. One concerns the relative efficiency of the cutter and jet, for disintegrating and delivering the material to the suctions. Of course, in any tenacious material, such as clay, the cutter is indispensable; but it is clearly established that in the loose sand which almost exclusively forms the bars of the Mississippi, the jet is equally effective, delivering as large a percentage of solid material to the pump, while it costs less, weighs less, and requires less power to operate. It is also less liable to accident than the cutter; for when other material than sand is found it is either an embedded drift log, a boulder of concrete gravel, or some other solid object, which no machinery can deal with. From around and under these the jet removes the sand, allowing them to drop below the bottom of the cut.

An additional dredge is now under construction which will be provided with the means of self propulsion, by which addition it is hoped to largely dispense with the services of a tender in moving the dredge from bar to bar. Although the arrangements for moving the dredge while at work on a bar are already very efficient, it is hoped that this operation may also be facilitated.

Experiments are soon to be made with a side delivery pipe, from 100 to 200 ft. long, instead of from the stern through 1 000 ft. of floating pipe which is generally necessary to reach the lower pool. The cut made through the bar is not usually in the exact thread of the current, and there is, therefore, generally an up-stream and down-stream side to the artificial channel. It appears that if the excavated material could be delivered on the down-stream side, it would either be taken away from the cut by the current, or, if it remained where deposited, would act as a training dike, and serve to increase the natural scour

Mr. Harrod. in the channel. The saving would be in the increased output, with the less friction in the shorter pipe.

In ordinary cases the immediate result of opening a channel through a bar, either by dikes or dredges, has been to draw down the upper pool, and increase the obstruction of the bar above; but owing to the dimensions of the Mississippi, the great low-water discharge, the slight fall, the distance between bars, the capacity of the intervening pools, and the small relative increase of channel section required for improvement, there seems to be no reason for anticipating such results. If realized, there is no reason why they should be more intense with dredge than with dike work.

It is true of this work, as it is of all engineering work, that the degree of success is quite dependent upon the judgment with which the artificial channels are located. It is certain that the highest degree of skill, knowledge and judgment is required in the engineer to whom this part of the work is entrusted. To what he has acquired in the schools must be added a close knowledge of the physics of the Mississippi River, which can only be acquired by experience, and also the trained eye and judgment of the pilot. He must detect any natural preference of route across the bar which the river may have; he must know how this can be developed, or modified, to meet the demands of navigation, and must anticipate what movements or changes may occur, either from natural causes or as the result of dredging, to threaten or favor his project.

When this method of low-water improvement was first adopted, the study of the subject was almost exclusively intrusted to the late Henry Flad, Past President, Am. Soc. C. E., who brought to it his large experience, great ingenuity and intense power of application. The first boat was built very largely on his plans. It contained several experimental features, and after these were subjected to a process of selection and elimination, there remained the solid parts which, practically unchanged, have entered into all the later constructions, as described by the author. To Colonel Flad, perhaps, more than to any one else, is due the success of hydraulic dredging as applied to the sand bars of the Mississippi River.

Mr. Le Conte. L. J. Le Conte, M. Am. Soc. C. E.—This excellent paper is a very welcome contribution to the knowledge of river works, and announces good news in the way of very important steps taken in the direction of speed and economy in accomplishing the great problem of maintaining good low-water navigation, at a moderate annual expense.

The engineering troubles mentioned are on a stupendous scale, as compared with those encountered on ordinary rivers, but are, nevertheless, quite similar to those experienced on all rivers having a large amount of sandy bed flow. Each year, as the flood waters subside, and the low-water stage approaches, the wide sheets of shallow water,

Mr. Le Conte.

passing over the crests of the reefs, begin to subdivide into channels, more or less marked, the locus naturally selected being at places where the material on the reef happens to be more easily eroded than elsewhere. Should several channels develop across the reef, with no particular difference as to depth or width, the judgment of the engineer is often sorely taxed to tell which one of the number to select for improvement. On one hand, free navigation demands a reasonably straight crossing, while on the other, experience shows, and it too often happens, that the square crossing at right angles to the general trend of the river, is nevertheless the easiest and most reliable channel to improve. This abnormal position arises from the natural fact that, as a rule, the lightest material is generally, if not always, deposited at the up-stream flank of the reefs. All an engineer can do, in such tentative works, is to study and cautiously follow in the footsteps of natural erosion as the waters subside. To do otherwise would be courting humiliation and wasting money.

The Long scraper mentioned by the author has been used with success on the upper rivers in California in deepening chutes across gravel bars; but in the lower rivers, having wide sandy crossings, the use of the scraper has not been a success.

The temporary wing dams mentioned by the author are certainly very important inventions, which will undoubtedly be of great value in the general conservancy of low-water navigation. They are capable of doing a vast amount of work in a short space of time, the main points to be considered. The practical application must be tempered with much judgment, however, otherwise new bars will be developed by the disturbance of the level of the pool waters, and the new bars created may require a large amount of unexpected work.

Tree-dams, referred to in the paper, constitute a very cheap and effective means of improvement; the up-stream ends or butt-ends being anchored down on the line of the dam. Such dams, of course, last for the season only, as a rule, and are washed out by the following flood waters; but in some cases it is practicable to build them on the making side of the bar, and thus the useful life of the dam may be prolonged many years by making small annual extensions.

The writer is particularly interested in these important dredging results, inasmuch as he has been closely associated with hydraulic dredging plants at the Oakland harbor-works, California, since 1883. His first paper on this subject was read before the Society on December 5th, 1883.* Since that date every imaginable variety of "cutter" has been tried with more or less success in its particular line of duty. The hydraulic jet admits of wide application, and is eminently suited to bring about the complete disintegration of all classes of material, except rock and tough rubber-like blue clay.

* *Transactions*, Am. Soc. C. E., Vol. xiii, p. 9.

Mr. Le Conte. There is a great variety in the style of centrifugal pumps in use, and this variation in practice is due chiefly to lack of comprehension on the part of those who may be called clean-water pump men in contradistinction to the dredge-pump men. The former always insist on the use of small runners at high speed, whereas experience shows, that for dredging work large runners, with faces as wide as the diameter of the suction pipe, and moderate speed give the best results with lowest costs for wear and tear. As soon as the water column becomes heavily charged with material, sand particularly, the element of friction is developed enormously, which fact weighs heavily against the use of small-sized pumps. Again, dredged material is notoriously full of all kinds of foreign matter, and, as a rule, all that which enters the suction pipe must pass through the pump. Any attempt to intercept the same by straining devices will surely end in failure due to clogging. The exception is in the case of stone, which can be caught in a depressed trap. The reverse-curved arms have been used in the Australian dredges built by George Higgins, M. Inst. C. E., and are highly spoken of. The runners of the larger ones are 8 ft. in diameter, and have developed unusually high efficiency at moderate speed, a matter of great moment for dredging.

Mr. Wheeler. W. H. Wheeler, Esq.—Reference has been made in the paper to the removal of shoals in rivers by a mechanical system of erosion, and the transport of the material eroded by the action of the water; a description of some of the devices which have been used from time to time for this purpose being given. The author's conclusion appears to be that none of these machines has satisfactorily answered the purpose for which it was intended.

Having spent a great deal of time in experimenting and investigating the best means of applying the transporting power of water to the deepening and improvement of river channels, the writer is pleased to have the opportunity of stating the results at which he has arrived.

It is a matter of common observation that all rivers during land floods are charged with a large quantity of alluvial matter which is carried to the sea in suspension; and their turbid condition then is practical evidence of the ability of water to transport material. At other seasons, when the water flows away to the sea comparatively clear, there is a waste of energy when there are shoals in the bed of a river which require to be removed, or where the channel can be improved by being deepened.

Flowing water has generally a large amount of undeveloped power, and glides over shoals without exercising the erosive action due to the velocity at which it is running. A very slight cause will lead to the disturbance of the particles of which such shoals are composed, and will place them in suspension in the water. This latent power may, therefore, be changed into active energy by mechanical erosion and

diffusion, and thus the river may be made the agent for its own improvement. Mr. Wheeler.

It is unnecessary to enlarge on the capability of flowing water to transport material, as this subject is fully dealt with in the chapter on the transporting power of water, in "Tidal Rivers."*

An investigation of the various machines which had been invented for the purpose of mechanical erosion led the writer to the following conclusions: These machines failed either, (1) in completely churning up the material and incorporating it with the water; (2) in reducing the particles to a sufficient degree of fineness to allow them to remain in suspension after being once set in motion; or (3) by creating a false current, in the vicinity of the machine, which carried away larger particles than the normal velocity of the stream could hold in suspension, and these particles, therefore, settled in the channel as soon as they got beyond the sphere of the increased current. Harrows and similar devices fail to fulfill the first and second conditions, and screws of steam boats, which, under certain conditions have been found of use in disturbing and breaking up shoals, come under the third condition.

The type of eroder evolved, after a series of experiments with models of various shapes and designs, consists of a cone-shaped cutter, having a number of steel blades fastened vertically on the periphery. This cutter is attached to the end of a vertical shaft connected by bevel gearing with another shaft carried on a horizontal ladder working in a well in the center of a barge, and driven by a steam engine on board. The ladder, which is hinged at the upper end, rises and falls as required in order to adjust the cutter to the depth of water in which it is working. The barge is warped forward and sideways by chains running on winches worked by the engine. The cutter works against a fall of from 2 to 3 ft., and, as material is detached by it from the shoal, the pieces are rapidly rolled round and round by the centrifugal current created by the cutter, and rubbed against the face of the shoal until the particles are reduced to a size of sufficient fineness to be carried away by the current. By this means the cutter automatically adjusts the size of the particles to the velocity of the stream, the particles not flowing away until they are capable of remaining in suspension in water having a less velocity than that of the stream into which they are discharged. If the current has a low velocity, say 1 mile an hour, the particles continue to be rolled about in the vortex at the cutter until they are reduced to a size of 1 000 to 2 000 to a lineal inch. The cutting of the face of the material to be removed is more due to the disintegrating effect of the small pieces of soil being continually rubbed against it by the centrifugal current than to actual

* "Tidal Rivers, Their Hydraulics, Improvement and Navigation," by W. H. Wheeler.

Mr. Wheeler. contact with the blades of the cutter. The material thus placed in suspension has been carried to sea for a distance of several miles without any redeposit in the channel.

This eroder gives the best results when working in shoals of alluvial matter or in clay. In sand shoals the particles are too large to remain in suspension in the channel after leaving the eroder. The machine, however, has been successfully used in deepening shoals consisting principally of coarse sand and shells mixed with gravel. In this case, the disturbance caused by the eroder set the finer particles in motion and mixed them with the flowing water, the coarse sand and gravel dropping to the bed of the channel, which, for the purpose, was excavated to a greater depth than that required for navigation.

A machine made on the principle here described, and placed on a steel barge built for the purpose, has been successfully at work for the last eight years in removing shoals of alluvial matter which make up, from time to time, in certain parts of a tidal navigable river which the writer has under his charge. Owing to the position of these shoals and the difficulty in removing the material, the cost used to amount to about 18 pence per cubic yard. With the eroder in use, the cost has been reduced to 1 penny per cubic yard. In other parts of the same river shoals consisting of compact beds of clay, mixed in some places with chalk, and in others with peat, have been eroded and cleared away to depths varying from 1 to 5 ft., at a cost of from $1\frac{1}{2}$ pence to 2 pence per cubic yard measured *in situ*.

The eroder commences working on these shoals on the ebb tide, as soon as the water has fallen sufficiently to allow the ladder to reach the bottom.

It is not contended that such a machine is adapted to rivers of the magnitude of the Mississippi, or in situations where the amount of work to be done warrants an outlay on a large plant. In such cases, suction dredges, fitted with cutters and delivering into hoppers, to a certain extent fulfill the same purpose as an eroder, as the smaller particles of material disturbed by the cutter either float away directly in the stream or in the effluent water from the hoppers. For this reason, when there is sufficient current and the river water is not in a turbid condition, the more the cutters disintegrate the material, the greater will be the proportion of it transported by the stream, and the less the proportion to be carried by the hoppers. It is due to this cause that, in many dredging operations in silt and alluvial matter, it is found that the quantity carried away in the barges is less than that measured *in situ*.

There are, however, numerous smaller rivers, where the traffic is not sufficient to warrant the outlay required for the purchase of expensive plant, nor the revenue sufficient to pay the cost of hiring and working ordinary dredges, and in these the navigation could be materially improved by an eroder of the kind here described.

W. S. MITCHELL, Esq.*—In the effort to deepen the low-water channels of rivers flowing over shifting bars or "crossings," it is probable that temporary or portable dams or jetties were suggested at an early date. Their practical use, however, is not believed to have been extensively tried in a large river until, within the past two years, in the Mississippi between the mouths of the Missouri and Ohio Rivers, where they were used on such a scale as to warrant a fuller description of their evolution and effects than is given by the author in his notice of them as "current deflectors," which, by the way, they are, only in a limited sense, their "deflecting" effect being of minor importance. They have been used as "contractors" to cut off a portion of the cross-section by giving an artificial crest to the bar on which they are placed, as close to the steamer channel as possible; this slight damming resulting in an increase of a few inches in the slope over the shoal, and this has been sufficient to gradually deepen the channel across it. Mr. Mitchell.

It is true that in placing them, the jetties have usually been given an inclination down stream toward the end of the shoal, but, although various angles have been tried, this has proved of little value. Latterly, the angle has been made very flat, and no hesitation has been felt in changing the direction of the jetty, or any portion of it, to take advantage of the irregularities of the river bottom and thus avoid crossing very deep water. A depth of about 10 ft., with good current, has been found to be the practical limit in which such light and temporary structures can be placed quickly and cheaply. They have been successfully carried across depths of 16 ft. to 20 ft., but the piling supports and foot-mats have had to be so greatly increased in strength that the cost was excessive.

These structures, in their evolution from plank aprons hung over the sides of barges or small flat-boats moored in the desired lines, to corrugated steel panels resting on the bottom on small fascine-mats, or plank-mats and supported at their tops by piling connected by stringers, have been fully described in the reports of the Chief of Engineers, United States Army, for 1895, 1896 and 1897, and will receive further notice in that for 1898.

In all, on fifteen bars, twenty jetties, aggregating more than 3½ miles in length, have been placed. In the past two years, 10 000 lin. ft. of steel panels (costing about $3.50 per lineal foot or 20 cents per square foot) have been kept on hand for use as needed.

In the low-water season of 1896, 6 500 lin. ft. of jetties were built in seven lines on six shoals, and in the fall of 1897, 9 300 lin. ft. were built in nine lines on seven shoals; their cost having been reduced to about $3 per lineal ft. of jetty constructed. This includes all charges for superintendence, labor and plant, placing, maintaining, removing

*United States Assistant Engineer, St. Louis, Mo.

Mr. Mitchell. at close of season, storing when not in use, repairing, loss and deterioration of panels and plant, towage, etc.

A party of seventy men with three pile-drivers and two derricks will place about 250 ft. of jetty per day of eight hours, and in the same time will remove about 400 ft., including the drawing of all piles and loading both piles and panels on barges.

In placing the jetties a great variety of positions has been tried. A few have started from the river bank or from dry bars, jutting out into the stream, but most of them have been placed in mid-stream as close to the channel as possible, and usually, though not always, on the lower side of it, leaving the latter to pass at either end it might choose. At Danby Landing a jetty 1 200 ft. long was placed, with the channel passing in the 300-ft. space between it and the Missouri shore, and the result was the silting up of that passage and the formation of a new channel close to the jetty in the 700-ft. space east of the line. At Platin Rock the jetty (2 200 ft., the longest yet built) preserved and deepened a channel that passed directly under its full length. Jetties have also been tried in series like spur dikes, and in pairs acting as funnels.

In general, their effect has been remarkably good, the channel depths being increased by from 1 to 3 ft., and also being maintained, even with a steadily falling river, which in the past year reached the extraordinary stage of 1 ft. below standard low water.

In addition to the deepening of the channel proper there is always considerable scour immediately above, but so close to the structure that it cannot be used as a channel even by the smallest boats, as it is rarely more than 30 ft. in width. It is this cut that is usually dilated upon by those river men who are advocates of various forms of jetty identical in principle, such as lines of sunken barges, barges from which heavy sheet piles are dropped, etc., but it cannot be used while the jetty is in position; and, on the removal of the latter, it immediately silts up.

Another claim by these advocates is that their forms of jetty will accomplish the desired work in a few hours or days, and that the plant may then be removed for use at other places, leaving a permanent and constantly deepening channel through the bar last occupied. Unfortunately, experience does not confirm this, but, instead, it has been invariably necessary to keep the jetties in place during the entire season to maintain the gain in depth secured by their use, and they have been removed only on the approach of ice. To do this with the forms referred to, and on the scale needed, would involve such enormous outlay for plant and operation as to be prohibitory.

Jetties worked in conjunction with some of the several forms of dredges have been tried and are very successful in maintaining the depths secured so much more quickly in that way. This has sug-

gested the thought that it may be possible to build a jetty, either in whole or in part, of the sand thrown out by the powerful suction dredges now coming into use. If this can be successfully accomplished, it will greatly cheapen and simplify the maintenance of dredged channels in such rivers, because, as a result of the moving sand of the river bottom, their tendency is to fill up at once upon the removal of the dredge. Occasionally a dredge-cut, without other work to maintain it, may deepen and improve, and become the permanent channel for that low-water season, but more often it will require a repetition of the work of the dredge, which will thus be forced to patrol its district, cutting channels wherever needed and repeating the work as many times as may be necessary. Mr. Mitchell.

In addition to the jet dredge noted by the author (pages 238, 239), good results have been secured by the use of the wheels of powerful tow-boats anchored on the bars by spuds. The wheel is turned at any desired rate (usually $\frac{1}{2}$ to $\frac{3}{4}$ full speed), the race of water washing the sand rapidly down stream. Depths of 8 ft. to 10 ft. have been quickly attained in this manner. The tow-boat *General Abbott* is fitted with two powerful duplex pumps, 20-in. and 12 x 24-in., discharging through the stern rake just forward of the wheel, through two 4-in. stirring nozzles lowered close to the sand, to aid the wheel in cutting into the bottom.

This boat has been very useful in cutting off the points of reefs and in removing mud-lumps, thus straightening channels which otherwise were tortuous and difficult.

All these jet, stirring or washing dredges, however, are at distinct disadvantage on wide bars, in having to move material more than once before its final disposition by the current in the nearest pool below the shoal.

The two new suction dredges mentioned as designed by Major Handbury, for use between the Missouri and Ohio Rivers are now ready for service. They are powerful dredgers, and that they may be expected to do effective work during future low-water seasons, is justified by their highly successful inspection trials when, under working conditions, a maximum discharge of 1 200 cu. yds. of solids per hour was obtained with each.

The swivel joints in the discharge pipes at the stern of the dredge and the pontoons, arranged to swing under the pipe, are believed to be novel and a distinct advance toward the solution of the problem of handling the long discharge lines of suction dredges.

By setting the pontoons at an angle with the current ("lee-boarding" as it is termed by the river men, and they may be so set, singly or all together by means of rope bridles running from the pontoons to the dredge capstans), the whole pipe line has been swung out at an angle of 48° from the dredge, and a spread of 80°, or 670 ft. between

Mr. Mitchell. the ends of the two lines, has been obtained. With greater experience, this distance can probably be increased to 800 ft., thus enabling the discharge to be placed 400 ft. on either side of the dredged channel without the use of piles or lines to haul the pontoons into the desired position.

Mr. Coppée. H. ST. L. COPPÉE, M. Am. Soc. C. E.—The dredge, aside from the simple act of taking from the bottom or sides of a ditch or water-way a certain given amount of material, has had a moral and political influence hardly secondary to the railroad.

In addition to reclaiming harbors, and deepening and regulating rivers and canals, it has hurried the advance of civilization by increasing the facility for navigation and commerce between far distant lands, cutting the very sinews of race prejudice and religious intolerance, and bringing the antipodes together.

Contemplate the East of to-day and prior to 1859, when Ferdinand DeLesseps struck the first blow on that barren neck of land that ten years later was divided by a canal connecting the Mediterranean and the Red Seas—the new and brilliant West with the shadowy Orient. European civilization, customs, dress, thought and education, then but surmised in that land of compulsory ignorance and superstition, are now almost universal.

The history of dredges and dredging, and their evolution from the very crude beginnings in the not remote past to the great machines described in this valuable paper, is extremely interesting.

The *Century Dictionary* gives the root of the word dredge as *drage*, meaning to draw or drag. The first dredging tools were purely drags, drawn along the bottom. To-day dragging plays no part in the operation of dredging with the modern machine.

The principles which govern the operations of the various dredges were probably applied daily by primitive man, and most of the types now in use were illustrated by his actions before the dawn of civilization. He is seen in his endeavor to enlarge the basin of the spring that bubbles from the earth near his rough abode, scraping the sand or leaf mould from the bottom, making of his foot and hand a crude scraper dredge; or perhaps holding with one hand to a tree or vine, and, with the other, scooping up the material and throwing it on the bank, as in the case of the scoop or dipper dredge; or standing astride the pool, reaching down his muscular arms and clasping double handfuls of earth as the clam-shell digger does; or, where the pool is more extensive, and its waters supply a community, with his fellows forming a human conveyor to transport the more tenacious material from its bed to the bank, naked arms, hands and bodies performing the functions of an endless chain.

This latter mode of dredging was practiced as late as 1864 on the

Suez Canal in the incipient stages of the work, when Fellah labor was furnished by the Khedive of Egypt. Mr. Coppée.

Consul Farman states, in an interesting report to the State Department, May 18th, 1881:

"Two short canals, which supply the City of Alexandria and the small District of Beharah, required for their ordinary cleaning each year twenty-five thousand to thirty thousand persons, for a period of from forty to fifty days. One of these canals was re-excavated by Mohammed Ali in 1819 to 1820, who employed in its construction two hundred and fifty thousand (250 000) laborers for about one year, of whom twenty thousand (20 000) are said to have perished from sickness and hunger. All the labor cleaning the canals and repairing the dikes is obtained by what is known as the Corvee, a system of forced labor. The inhabitants of the Fellah class are taken in mass from their villages and compelled to work forty-five days or more, if required, under overseers and without remuneration * * * Women and all the boys and girls down to the age of eight or nine years are seen carrying baskets of earth on their heads."

The canals that are dug are cleaned by taking out the accumulation of deposit in baskets, carried, for the most part, on the heads of the women and children. In many places there is considerable water and a very thick mud deposit; this is removed by a man standing in the water and working out with his hands pieces as large as he can conveniently raise, which he tosses to his neighbor, standing near to or on one side of the bank, whence they are sometimes passed to a third or even a fourth person, until they are removed to a sufficient distance. "Even at the average pay for agricultural labor in Egypt of 10 cents per day, such dredging would not be excessively cheap."

Again, in his report on the Suez Canal*, Professor J. E. Nourse, U. S. N., states:

"The lake to-day is a large marsh of salt water resting on clay; in spite of its character, it has not proved specially unhealthy. The line of the canal here for forty-four kilometers presented difficulties in place of less work, for its varying depth presented obstacles in the way of any connected work; but the vigorous race of fishermen on its borders, accustomed to the sun and the mud, scooped up the clay in their hands, rolled it into balls on their chests, and then carried it off on their backs with their arms crossed behind. In this way they raised about four hundred thousand (400 000) cubic meters."

In some parts of China, where even at the present time can be seen the customs and methods of an ancient world, the dredging and levee building is, to a considerable extent, carried on in the same primitive manner.

The writer is indebted to Captain W. E. Hunt† for the following description of a dredging outfit, in a letter received in January, 1894: "They attached a bamboo pole to a scoop-shaped wicker basket; the men and women have a mode of fastening it to their backs and scoop-

* Senate Ex. Document No. 198, 1884.

† U. S. Ex-Consul to Hong Kong.

Mr. Coppée. ing up the material from the bottom. From the basket they throw the mud out into a small boat, the whole family, children included, assisting in the operation. (The family lives on the boat.) After obtaining about one hundred pounds of mud, they pole the boat to deep water, where it is discharged."

In Mr. Rickard's article, "Gold Dredging in New Zealand,"* he states that there was in use about thirty odd years ago a spoon made of a piece of hide fastened to a ring of iron connected with a shovel blade and attached to a long handle, with which the gold-bearing sand was scooped from the bottom of the river. At points where the river became too deep for wading, a punt was employed, and the hand power was aided by winch and tackle (not unlike the Chinese method).

What a contrast to the mammoth dredges of Europe and America, which in a day, with their huge arms and teeth, plow deep channels through the solid earth, or with the suction of their great centrifugal pumps, draw from their resting place hundreds of tons of the ocean's sands.

Undoubtedly in the ancient civilizations that have sprung up, matured and passed away, leaving but faint traces of their greatness, engineering appliances of many kinds were used, among them the dredge in some form. That this dredge was more than a crude type of the existing machine is hardly possible, for in the very seats of ancient prosperity, commercial and intellectual, there are found to-day the most primitive machines, no trace of former greatness in engineering methods or appliances being discernible. The harbors of the Phœnicians, the first great navigators and commerce carriers, have been so obliterated by the ocean, that to-day it is said, with one exception, there is no safe port for vessels of modern times in any of their formerly great roadsteads.

In a very interesting paper on the construction and use of the hopper dredge, by Alexander Charles Schonberg,† are to be found some valuable notes on the history of dredges. Mr. Schonberg states that over one thousand years before the Christian era, artificial harbors existed that were probably originated and maintained by the Phœnicians, as they were the only great navigators at that early period. Their boats were flat bottomed, drawing about 4 or 5 ft., and of 50 to 60 tons burden. In these small vessels they carried the rich products of the soil, and of art and manufacture, to the remotest parts of Europe, Asia and Africa, founding great commercial ports on many of the great water-courses of the Eastern Hemisphere.

The origin of the harbor on the coast of Great Britain, Mr. Schonberg states, was a crude haven of refuge, constructed by piling up a

* *Engineering Magazine*, June, 1894, p. 349.

† Read before the Civil and Mechanical Engineers' Societ y, England, March 14th, 1888.

few rocks, or other material, as a breakwater, behind which these small vessels rested during stormy weather. In time, this small wall was pushed out to deeper water, its dimensions being increased until it finally protected a harbor of large extent and great commercial importance. Perhaps, behind these walls in those early days some simple kind of dredge was used, but there is no authentic record of such. After the Phœnicians, the Greeks and Romans took their place as the navigators and commercial carriers of the eastern world, building sea and river works to further their projects of conquest and gain, and on the decline of the Roman power, the Venetians continued the construction and improvement of harbors. Still, there is found no record of dredging operations (though undoubtedly such were carried on). Mr. Coppée.

Weale's papers on Engineering (1843) notice a work by Verantuis, bearing date 1591, in which there is described a dredge consisting of two pontoons lashed together with two spoons between them working in opposite directions by means of a walking wheel, the raised material falling into a hopper barge. This is considered the earliest form of the primitive dredging machine.

From the crude tools, paddle, rake, scraper, plow, harrow, etc., used in the sixteenth century in England and on the Continent, little advance was made until the close of the eighteenth century, when steam was beginning to be applied to machinery, dredges included.

In 1796 it is stated that a Mr. Grenishaw, of Sunderland, applied to Messrs. Boulton and Watt for a steam engine to run dredging machinery for the purpose of cleaning Sunderland Harbor. The machine was built in the following manner: A 4 H.-P. engine was placed in a flat-bottomed boat 60 ft. long, 20 ft. wide and 6 ft. deep, with a draft of 4 ft.; the weight of the engine and machinery was 23 tons; the capacity was four spoons, each containing 1 ton of material when full, lifted to the height of about 10 ft. per minute. With the exception of the crude machine mentioned by Schonberg as being invented in 1618, this is probably the first steam dredging machine ever constructed. The spoons in this dredge were in the form of truncated cones, with the small end closed, the open end having a spade bit. The spoons were made of hide leather with an iron rim (somewhat similar to the New Zealand scoop before described). The engines had a 12⅛-in. cylinder and 3-ft. stroke, and made 30 strokes per minute, and were of the form called bell-crank engines.

The editor of *Engineering News* states that Oliver Evans in 1801 built in America a floating dredging machine operated by the first successful double acting high-pressure engine ever made. By putting wheels under his boat and connecting them with his engine, he propelled this nondescript craft 1½ miles overland to the point of launching.

With the exception of one type of dredge, which seems to be indigenous to America (the dipper or scoop), the history of dredging in

Mr. Coppée. the nineteenth century has been quite similar on both sides of the Atlantic. First the scraper, plow, jet, etc.; then the clam-shell digger (also the dipper in America), then the bucket ladder, followed by the hydraulic dredge; each type having numerous modifications to suit the conditions under which they operate and the special duty for which they are designed.

The first use of the dredge in the United States seems to have been in the construction and maintenance of canals.* Canal work is mentioned as early as 1770. The James River Canal was constructed in 1785 and the Dismal Swamp Canal in 1794, the Merrimac River Canal in 1792 and the Carondelet Canal in Louisiana in 1794, the Charleston Harbor and Santee River Canal in 1802. Until 1824 there was no established United States Engineer Corps, and up to that time little or no work on river or harbor improvement had been undertaken.

William P. Craighill, Past President Am. Soc. C. E.,† states that as late as 1853 in this country there were few dredges. The Government advertised for bids for dredges to improve the harbor of Baltimore for two or three years, but no contractor would submit a reasonable bid. It was, therefore, necessary to construct dredges of the Osgood pattern, also dumping scows and a tugboat. The Osgood dredge was the simplest form of the scoop dredge, the first steam dredging machine generally used in America. Thus it is seen that the more general use of dredges proper and their development to machines of great perfection, to operate under varying conditions, is confined to comparatively recent years. In little more than a century the crude rake of the Clyde contractor has been changed for the most complete modern dredge, moving in some instances as much as 10 000 cu. yds. in twenty-four hours.

A few years ago (1872) the hydraulic dredge was hardly more than the embryo of the machine in its present fully developed form; the simplest application of the principle consisting of a barge, a centrifugal pump with suction and discharge of the simplest form. The dredges of the Mississippi River Commission are probably the largest and most effective in the world. The value of their work is no longer problematical, though, on one or two crossings, they have not been altogether successful. On a great majority they have been entirely so. The trouble seems to be, not in the work of the dredge, but in the difficulty of locating the cut through the crossing to the best advantage, and foretelling the action of the currents, both forming and reducing the bar. All the little idiosyncracies of the great river where these dredges work may not be known, but as time goes by and experience and data accumulate, the general and perhaps specific law of

* "The Beginnings of Engineering," by J. E. Watkins, Assoc. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. xxiv, p. 309.

† "Some Observations on the Subject of the Improvement of Several of the Rivers of the Atlantic Coast." *Transactions*, Am. Soc. C. E., Vol. xix, p. 234.

flow over the bars will be developed, and less power and time will be wasted in accomplishing greater results. Mr. Coppée.

The author has not given the cost of dredging with these machines, probably because of the difficulty of determining what material is actually excavated and conveyed by the dredge and what removed by the current.*

It is interesting to note that the jet agitators have proved more satisfactory than the mechanical cutters. It was the opinion of the writer that the reverse would be the case, but the reduction in weight and care of machinery, and the effective work of the jets, have proven beyond all doubt the superiority of the latter on the sandbars of the Mississippi. In fact, in a number of instances, the dredges have worked well without either.

When the great dredge *Beta* was completed, tests of its capacity were made, as shown by the author, most of them lasting less than a minute. These tests were very misleading. After the dredge was put to work, its capacity for continuous operation was found to be far under the figures given by the short-time trials. In the case of the new dredges, the capacity and efficiency tests are also of short duration, and are but a poor indication of what the dredges will actually accomplish under the average conditions of work for which they are designed.

It is the writer's experience that very inferior dredges will often give great results for a few minutes under favorable circumstances, but will show weakness and inefficiency in a day's run.

The changes to be made in the *Beta* will add to its effectiveness and should reduce the cost of operation. The great draught, augmented by the weight of the cutter engines and other machinery that will be removed was much to its disadvantage. As the author states, the wear and tear of the cutter machinery, to say nothing of the power required, added largely to the expense.

The writer examined this dredge about the time it was tested, before being accepted from the contractor, and was much impressed by its great size and powerful machinery, and the perfection of detail, which is rarely seen in machinery subject to such shocks.

A. F. Woolley, Jr., Esq.—The dredge *Ram* was built in 1893 to work in what is known as Old River—virtually the mouth of Red River. The conditions under which it was to work were quite different from those which would be encountered in the Mississippi, the classes of material to be handled running through the various grades of very soft or semi-liquid mud, soft mud and sand mixed in strata, stiff blue gummy clay, gravel and fine, medium and coarse sand. Mr. Woolley.

In 1831 the Mississippi River, with artificial assistance, made what is known as "Shreve's Cut-Off," passing across a narrow neck of land

* For summary of operations, including cost, etc., see Chief Engineer's Report, Miss. River Commission, 1897, p. 3 612.

Mr. Woolley. and making an island of the former peninsula, which is now known as Turnbull's Island. Red River formerly emptied into the Mississippi at the upper end of the sharp bend forming the western extremity of this peninsula, and the Atchafalaya River was a small outlet of the Mississippi at the lower end of this bend. The old bed of the Mississippi has been filled in by the annual deposits, until there remains only a narrow and inadequate channel which hugs first one and then the other of the original banks of the old river-bed.

From the original mouth of Red River, around the upper or north side of Turnbull's Island, to the eastern end, is known as Upper Old River. From the original mouth of Red River, around the western end, to the Atchafalaya is called Red River; along the southern side of the island and out to the Mississippi is known as Lower Old River, and through the latter navigation is maintained.

It will readily be seen that at such times as the Red River is at a higher stage than the Mississippi, Lower Old River is carrying a portion of Red River to the Mississippi in the capacity of a tributary of the latter, the Atchafalaya carrying the remainder to the Gulf, *via* a a chain of lakes, and emptying 20 miles south of Morgan City, La. At such times as the Mississippi is at a higher stage than the Red, the Lower Old River becomes an outlet of the Mississippi, carrying a portion of its waters to the Atchafalaya, and in this case the Red and Old Rivers are both tributaries of the Atchafalaya.

It is to be noted, therefore, that sand is carried into Old River to a distance and in quantities varying with the velocity of the current, which is in turn quite erratic and dependent on the fluctuating stages of the Mississippi and Old Rivers, the maximum velocity being 10 miles per hour. The direction of the current is not infrequently reversed for short periods, shoaling up and thereby aggravating the evil from drifting sands, a portion of which would have passed through Old River and a larger portion of which would have been distributed over a large area, or deposited in some of the deep pools to be found in Old River.

There are two other and more serious obstacles to maintaining navigation, viz., the large sand bar annually formed at the junction with the Mississippi River, and sloughing banks.

The bar at the mouth must always be removed by dredging, so long as the current in Old River has no fixed direction. This bar, while varying much as to location and extent, has always been such that it was possible to locate and dredge a suitable channel, and this contains annually about the same cubic yardage.

Heretofore and up to the time of the writer's connection with this work the sloughing banks have been the cause of the greater portion of the dredging in Old River.

In the old bed of the Mississippi, and at distances more or less re-

mote from the present channel, there are large lakes which are filled from the annual floods. As their shores were built up, these lakes from year to year held water at correspondingly greater heads above the low-water level of Old River. The banks were entirely submerged during high water, and were kept thoroughly saturated during low-water periods, and consequently they never attained a stability that would permit their standing at anything but a very flat slope. Mr. Woolley

The banks ultimately attained a height of 25 or 30 ft. above low water in Old River, and sloughing occurred in such masses as to thrust large volumes of material into the channel from the sides. Where the section of the river was quite wide, the large masses of material, sliding down the slopes of the bank, though not able to reach the channel itself, were deposited on the flat portion immediately adjacent thereto. By virtue of their enormous weight, they forced up the bottom of the channel, owing to the unstable nature of the material, thereby forming what are locally termed "mud lumps," completely obstructing the channel which, probably an hour before, had contained from 10 to 12 ft. of water.

There was a time, no doubt, when it would have been impossible or impracticable to obviate this trouble, for during the early stage of this silting-up process the entire old river-bed was a perfect sea of liquid mud, and it was difficult to actually define the real shore lines.

Later, there was a time at which much, and finally practically all, of this sloughing and its attendant evils could have been obviated by simply keeping all these lakes thoroughly drained during the low-water season. The lakes were first systematically drained, by the writer, in the spring of 1894, and have been drained annually from that date to the present, thereby reducing the amount of dredging more than one-half.

The first season the writer was placed in charge of dredging operations in Old River, a thorough survey of the entire river was made, with numerous sections normal to the channel. These sections were connected with an accurate traverse line on top of the bank, and from this a complete contour map was prepared, embracing everything between the tops of the banks. On this map were established what the writer determined should be the fixed channel limits for future dredging operations, all of which received the approval of the District Engineer. These limits were determined with the following points in view—economical maintenance, ease and safety of navigation, tendency to maintain the original location from year to year, economy of first construction, and location where a pilot would naturally seek a channel.

Carefully studying the situation under the above qualifications in the order named, it was considered reasonable to locate such channel limits, with the exception of the channel at the mouth of Old River

Mr. Woolley. (known as Carr's Point Bar), Fig. 20. The latter has had to be located from year to year to conform to conditions in the immediate vicinity which are materially changed with each successive flood of either the Mississippi or the Red River.

The writer has always found, from year to year, remains of the channel dredged the previous year, and, while the channel may be obliterated at one or more points, it is a short, and the most direct, route to connect these disconnected ends, by dredging through the obstructions. After a period of four years the writer is prepared to state that this system of dredging, or fixed channel limits, together with the thorough drainage of the lakes, is to be credited with from 50% to 75% of what was formerly the cost of dredging at this location.

At the time the *Ram* was designed and built, it was intended to dredge out Upper Old River, which is filled almost entirely with a deposit of soft mud, such as the dredge was particularly designed to handle. The tests were made in this material, and showed a capacity somewhat in excess of 300 cu. yds. per hour.

The material handled under ordinary working conditions averaged about 150 cu. yds. per hour. The writer made a test embracing a period of $4\frac{1}{2}$ days on a reef of very compact fine sand, the average for this period being 178 cu. yds. per hour, although the depth of cut across the dredged channel was not uniform, and consequently the work accomplished was somewhat less than the maximum capacity of the dredge, even in this class of material.

This dredge has handled material for $0.025 per cubic yard. The work in some seasons has cost practically double this amount owing to the fact that the dredge was required to remain on the work, with a reduced crew, to redredge the channel should a reversal of the current renew the sand reefs.

All dredging in Old River is to a plane 7 ft. below zero of Barbres Gauge, and to a width of 80 ft. at the bottom, and at the mouth—Carr's Point—to a depth of 8 ft. below zero with a bottom width of 110 ft.

The gauge records throughout a long period show that the direction of the current during the greater part of the low-water period is from the Mississippi toward the Atchafalaya, and the channel at the mouth was designed to conform to this prevailing condition. The outer or Mississippi end of this channel was turned up the Mississippi to receive its supply unimpeded. The inside or Old River end of the channel was trained down Old River, so that it might discharge directly into the deepest water in Old River.

The channel across the bar at the mouth approximates in shape the arc of a circle, with a radius of about 650 ft., and serves the following desirable ends, which are not attained by any dredged channel along the main shore: It provides the shortest route between deep water in the Mississippi and deep water in Old River; it maintains a greater

Mr. Woolley.

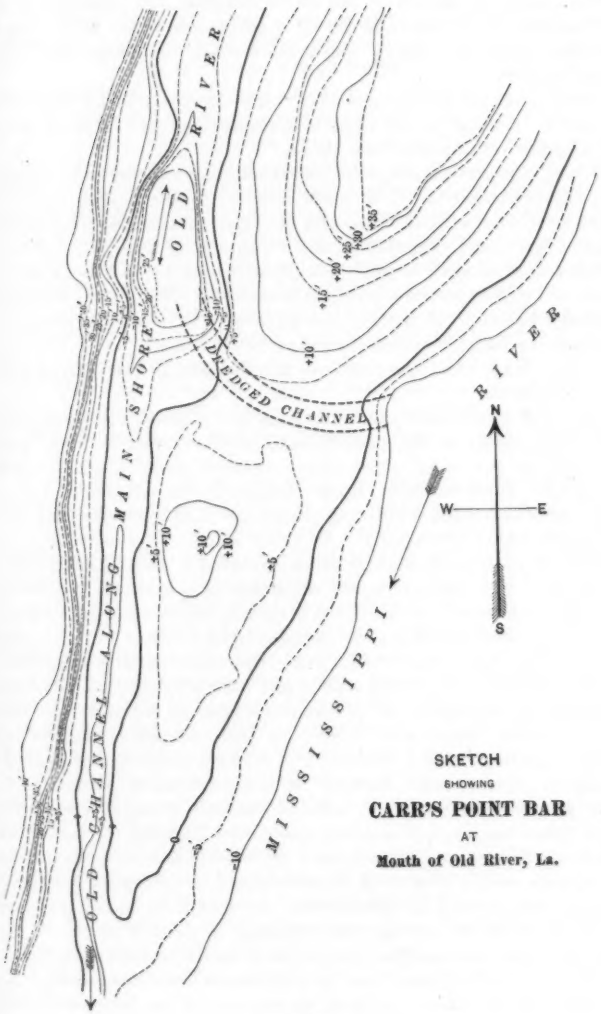


FIG. 20.

Mr. Woolley. head of water in Old River, as it takes its supply from the Mississippi, 4 000 ft. above the mouth of the shore channel, and conducts it directly across the bar into Old River; it effects saving of head, due to the surface slope in. 8 000 ft., and it more nearly maintains itself after being dredged.

The synopsis of the general plan of this dredge given by the author is correct. A copy of the detailed specifications may be found in the annual report of Captain John Millis.*

This dredge has proven to be an exceedingly satisfactory machine, all things considered. The most serious objection that could be raised is to the wooden hull, and the small dimensions for carrying so much machinery, together with the supplies of lines, etc., that are needed for a season's work. The present wooden hull is badly decayed, and it is expected to replace it next year with a steel hull of 25 ft. greater length. All parts of the machinery have proven themselves amply strong and well fitted for the service intended.

Briefly, the general description of the *Ram* and the method of working is as follows:

Hull of decked barge type, 95 ft. long, 27 ft. beam, 6 ft. 6 ins. deep; propelling engines of the modern high pressure, western river type, connected to the usual stern wheel; suction pump 15-in. Edwards centrifugal, three-winged runner, intake in the starboard axis of pump, discharge from bottom of casing and to the rear through pipe suspended below deck to a "Y" near after end of boat, and just forward of spud, the discharge being diverted to port or starboard at will by the "Y;" the out-board discharge is connected to a floating pipe line or to a short section (55 ft.), suspended by shear legs directly from the side of the boat; the pump suction carried by the cutter frame to the base of the cutter head; the cutter head supported at the forward end of the cutter frame, and driven by a 5-in. shaft, made in three sections, connected by claw couplings, all supported by bearings on cutter frame and driven by high pressure engines and sprocket gearing on bow of boat; cutter shaft connected to sprocket gearing by mitre wheels directly on bow of boat, to permit of the cutter frame being raised or lowered through a large vertical arc; cutter frame having a triangular horizontal section, its base being hinged to the bow of boat, its apex or forward end being suspended by wire rope tackle from an **A**-frame slightly overhanging the bow of the boat, the suspending tackle being connected to hoisting engines on forward deck for raising and lowering to desired depth of cut; swinging chain and cables leading from friction drums on bow of boat, through cutter frame near forward end, to anchors or dead-men on either side of channel; a spud on the axis of the hull 10 ft. from the after end, by means of the swinging cables the cutter is swung

* Report of the Chief of Engineers, U. S. A., 1894, page 2979, Appendix XX.

back and forth across the channel to be cut, with the spud as a center, and the distance between spud and cutter as a radius. Mr. Woolley.

For the work in Old River, with the strong current which usually prevails, it was found very difficult to use the pontoons, even where the depths outside the channel were sufficient, and there were many places where they could not be floated. It was then decided to suspend as great a length of discharge pipe as possible from the side of the boat, and discharge directly overboard. By keeping the dredge well to the side of the channel, on which the discharge was being placed, taking the full swing in the opposite direction, it was found that the material could be placed 60 ft. away, or on top of the flat shelf outside of the dredged channel. With the class of material encountered in Old River, it was found that a very small percentage of discharge returned to the channel. The ease of manipulation much more than outweighed the return of material to the cut, as compared with the stoppage and loss of time due to buckling and fouling of the pontoon line in shallow water.

In cutting the channel across the bar at the mouth, the discharge was always placed on the down-stream side, and although the material at this point is largely sand and gravel, a comparatively small amount of it returned to the cut.

The bar at the mouth had been cut through when 500 ft. of the proposed channel was high and dry above the water surface. In cutting through a dry bar the cutter head is lowered to the desired depth of channel, and worked forward just as fast as the material sloughs down the face of the cut. Of course, no material standing above the water surface could be cut through and not slough down the face of the cut, without much delay from moving back to clean up material that might have fallen behind the cutter head, unless blasting or other artificial means were used to throw down the face of the cut slightly in advance of the cutter. For this same reason no great depth of cut can be taken in very stiff clay without a considerable fouling of the channel behind the cutter head.

From the foregoing it will be quite evident that the depth of a single cut, within certain limits, has to be determined by the class of material being handled.

The dredge is always worked down stream, and the greater the velocity of the current, the greater the necessity for so doing, to prevent the fouling of the channel behind the dredge.

For all classes of material encountered in Old River, it is found that the channel behind the dredge does not differ less than 0.5, nor more than 1 ft. from the depth at which the cutter head is being worked.

When dredging in pure sand, the depth of clear channel behind the dredge and the depth of the cutter head varies from $\frac{3}{4}$ to $1\frac{1}{2}$ ft.,

Mr. Woolley. and much of this difference the writer attributes to material running from the sides. The *Ram* was fitted and designed to work with a walking or push spud, to be operated by steam, the spud to be raised and the foot set forward again after the dredge had been fed into the cut through the maximum movement permitted by the spud. This was never successful. The pushing gear was weak and defective, and the dredge was always thrown back from the face of the cut when the spud was being raised.

The spud is now used only to hold the dredge in place. When the spud is raised, the dredge is fed forward by the propelling engine. Under ordinary working conditions and depth of cut, the cutter head is swung across and back again over the desired width of cut, the spud is raised and the dredge forced ahead by propelling engines. The usual forward movement is from 18 to 24 ins. each time, and at about four or five minutes apart.

A careful study of the daily log of the *Ram* during the working season, since she was placed in commission, shows that seven and one-half out of every ten hours are actually devoted to dredging. This loss of but 25% of the actual working time is for all causes—minor repairs, moving swing cables forward to dead-men or shore anchorages, lowering swing lines for passing boats, raising cutter to remove débris or lubricate shaft bearings, and moving dredge to fuel barge for coaling bunkers when working without the service of a tender.

After four years' experience with this particular dredge, the writer is of the opinion that a machine of this type, which can devote 75% of its working time to actual dredging, is quite up to, if not above, the average. A dredge specially built to work in the open Mississippi, and not subject to many of the stoppages hereinbefore mentioned, should be able to average 8 to 9 hours' actual work out of every possible 10, or 19 to 21 out of every 24 hours.

In 1896 the Mississippi River Commission directed that the *Ram*, in addition to its duties at Old River, should care for the needs of navigation at Ford's Crossing, none of the other dredges built for use in the Mississippi being available for that locality.

Ford's Crossing (Fig. 21) is in the Mississippi River, about eleven miles below Natchez, Miss. This bar does not annually become a serious obstruction to navigation. In only about one of every three years has the depth of water been less than 7 to 8 ft.

In 1896 the greatest channel depth across this bar was but 5.4 ft. The crossing was rather abrupt, being at an angle of about 45° to the axis of river, and so crooked as to offer serious obstruction to the navigation of boats drawing even less than 5 ft. A survey was made and a contour map of the bar prepared. The channel was located by the most direct route from the upper to the lower pool, parallel to the thread of the current and practically over the nearest approach to any

existing channel. Numerous floats were run from the upper to the lower pool, their course being accurately located on the contour map. All available data were taken and noted in order to lay the proposed channel so as to coincide, as nearly as possible, with that which Nature would seem to indicate as her choice. The total length of channel dredged was 2 400 ft., to a depth of 12 ft. below extreme low water, with a bottom width of 100 ft. A navigable channel of 9.5 to 10.5 ft. was maintained during the season by going over the cut twice. The dredge was entirely inadequate to cope successfully with a bar of this magnitude. The conditions were unfavorable for a test of a dredge of this particular type and small capacity for bars in the Mississippi. Mr. Woolley.

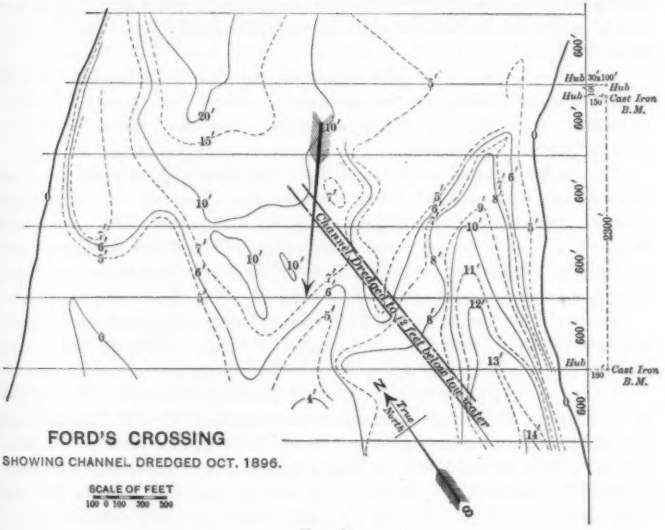


FIG. 21.

The river was falling during the first cut and rising during the second. There was a much greater back-fill and running of sand from the sides during a rising stage. The effects of dredging seemed to be pretty well obliterated five days behind the dredge on a rising river. With a falling river the channel behind the dredge maintained itself much better than had been expected. These conditions may apply generally to this and many bars in the Mississippi, or they may be as erratic as some natural locations of channels across bars.

The material encountered at Ford's Crossing was sand, mixed with about 1% of gravel. The sand was much coarser than that encountered at the mouth of Red River, and worked much easier, the dredge

Mr. Woolley. handling about 20% more per hour than at Red River, the average of solid matter being about 12 per cent.

The writer's experience in dredging large sand bars in the Mississippi River has been limited to this work at Ford's Crossing, with this comparatively small sand bar and small dredge; beside which the larger bars and larger dredges, in the upper Mississippi, are about as 1 to 10.

However, the experience gained at Ford's Crossing has, in the opinion of the writer, determined that the prerequisites to the successful dredging of a navigable channel through the bars in the Mississippi River are:

First.—Machinery of large capacity, able to burst through a bar in the shortest practicable time in order to secure the scouring action of the current before the channel behind the dredge shall have deteriorated.

Second.—A location of the proposed channel to conform, as nearly as can be determined, to Nature's choice, from which the slightest deviation will develop insurmountable obstacles, resulting in expensive and useless labor.

Before having had actual experience in dredging a bar in the open Mississippi, it occurred to the writer that placing the discharge 1 000 ft. away from the dredge was rather excessive. The experience at Ford's Crossing gave every indication that if the discharge had been placed 300 ft. away from the channel the distance would have been ample.

The sand on the bar at Ford's Crossing runs very much more freely than anything found at the mouth of Old River, owing to the larger grains composing the former.

It can be readily understood that the bars in the upper Mississippi are composed of a material that is subject to greater movement than that composing the bars in the lower Mississippi. The writer does not wish to be considered as implying that the discharge distance of 1 000 ft. has been adopted without careful tests, or merely because these dredges were fitted with this amount of discharge pipe.

The writer has seen no published results of tests to determine the practicability or economy of a shorter discharge distance than 1 000 ft., and mentions this with a view of bringing forth anything that may be available on this interesting point.

The following memoranda may be of interest as relating to the efficiency of the several parts of this machine, the alterations which have been made, together with others that it is proposed to make in order to place the dredge in thorough condition before the season 1899.

The cutter head has proven to be amply strong for all kinds of work. Many piles, sunken saw logs, steamboat wrecks, heavy oak checkposts in old sunken coal barges have been encountered and disposed of, and not a single blade on the cutter head has been broken.

Mr. Woolley.

The cutter head could be designed with larger openings for certain classes of material, which would increase very much the efficiency of the machine.

For the various classes of material, from stiff clay to sand, and including all kinds of débris, the present design of cutter head is well adapted.

The 15-in. Edwards pump has given great satisfaction, is comparatively easy of repair, has worn extremely well and is admirably adapted to this kind of work.

There is but one slight objection to the details of this pump: For the high speed required, the writer has found need for larger thrust bearings. With some minor alterations, and with water-jets, the writer has been enabled to run the pump at 260 revolutions per minute for eleven consecutive hours, with a vacuum of from 4 to 27 ins., without undue heating.

It is proposed to increase the bearing area of the thrust rings about 50% as soon as it becomes necessary to put in new rings.

The compound engines were built by the Bucyrus Company after their own pattern; high pressure cylinder 14½-in. by 20-in., low pressure cylinder 26-in. by 20-in., placed on a rigid, hollow-girder bed-frame.

The engines are driven at 130 revolutions per minute, and develop under ordinary working conditions, with 100 lbs. boiler pressure, from 170 to 190 H.-P. The engine and pump are connected by belt; the revolutions of pump and engines having a ratio of 2 to 1.

The first season's work developed the fact that the engine shaft was too light to carry the heavy driving pulley without heating its bearings, the shaft becoming flexible when running with full load and thus causing great vibration throughout the boat.

The shaft was made as large as housing could accommodate, the hollow cast-iron caps forming the top of the bearings were tapped and a stream of cold water constantly circulated through them. No further trouble was had from heated bearings.

The present wooden hull has proven entirely too small for the convenient manipulation of the machinery, and it is proposed to replace it with one of steel. The new steel hull will be 25 ft. longer, will contain ballast tanks on either side, to enable a greater length of discharge pipe to be suspended from the side of the boat, and at the same time to allow the boat to work on an even keel, without the necessity of constantly shifting fuel from bunker to bunker for ballast, as is now done.

The propelling engines are capable of driving the dredge and a tow, consisting of a large fuel barge, with fuel for an entire season's work, as well as all pontoons and other necessary equipment, upstream at the rate of 6 miles per hour.

Mr. Haupt. L. M. HAUPT, M. Am. Soc. C. E.—This valuable paper is so comprehensive as to open a wide field to discussion, and one cannot do it justice in a brief contribution, with limited time at command.

There are several points to which attention is directed. Before submitting them, however, the writer would remark, *en passant*, that at the Annual Convention of 1892 he called attention to the fact that, unless the discharge of sediment at the delta was equal to or greater than that carried into the bed of the river by its tributaries and caving banks, the bed must inevitably rise. This proposition appears to be confirmed by the physical description of the river, showing a diminution in slope and absence of bars in the lower reaches, the coarser gravels being deposited higher up, and only the fine mud being carried to sea.

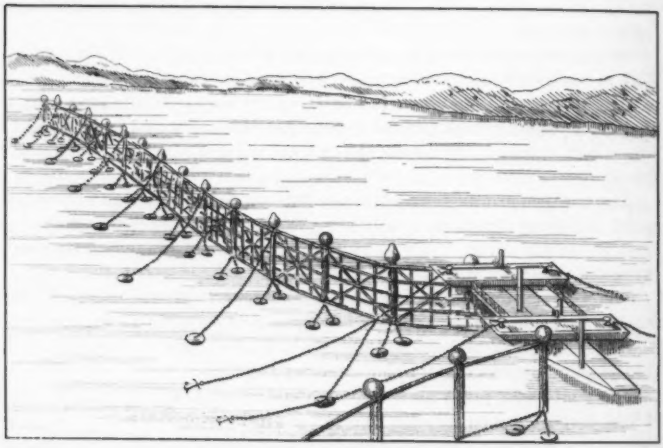


FIG. 22.

Under the subdivision of current deflectors, the author states (page 233): "In practice, it is a well-known fact that a barge anchored in shallow water will very soon cause the sediment to deposit." Etc.

On the contrary, it was found during the building of the St. Louis Bridge that the scows placed around the abutments produced a scour under them.

The writer also observed that the vessels lying alongside the bulkhead of the Atlantic Refining Company's wharf in the Schuylkill River, Pa., where the currents are sluggish, caused a well-defined hole to be scoured under their berths, while a ridge rising from 11 to to 13 ft. formed outside near the axis of the stream. The low-water depths along the bulkhead exceed 20 ft. Again, the writer made an

experiment on the Five Mile Bar, with current deflectors hinged to piles to test their efficiency, and within two tides the depths were increased from 9 to over 18 ft., M. L. W. Mr. Haupt.

The writer is, therefore, at a loss to understand the local or other conditions that have apparently produced such opposite results from current action due to vertical deflection.

The description of the canvas curtains is akin to the devices patented by the writer in 1886, and a reference to Fig. 22 will suffice to show the idea.

Again, the 5th class was clearly anticipated by a device tried by William P. Craighill, Past-President, Am. Soc. C. E., on the lower Susquehanna with very good results. It consisted of two or more boats or rafts, with vertical sheet piling suspended between them, to be used in trials for the proper location of a more permanent dike.*

The 8th class is also anticipated in the Brownlow weeds, so successfully tried on the Missouri River in 1878 for the purpose of contracting the river by creating artificial bars by means of these permeable dikes,† which proved so cheap and effective, as compared with the revetments.

The following extracts ‡ may serve to supplement this interesting digest by the author, as it describes devices to which no reference appear to be made:

"*History of Vertical Deflectors.*—Probably the earliest attempt made to apply a vertical deflection of the surface velocity upon the bottom was patented by General G. T. Beauregard in 1853. The device (Fig. 23) consisted of a large, rectangular wooden tube, open at both ends and having a wooden diaphragm or inclined plane extending from the upper edge at the inner end to near the lower edge at the outer, for the purpose of reflecting the surface current downward to act upon the bar. 'The excavator is to be anchored at the inner edge of the bar by weighting down the top.' Thus it appears it had no means of locomotion, the anchorage was very deficient, there was no assurance that it would always remain 'right side up,' nor that it would not be submerged by the scour at its ends and sides. It would probably soon have been dashed to pieces, capsized or buried. There is no evidence that it was ever tested.

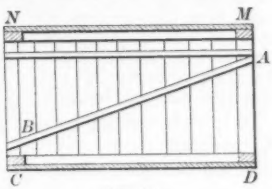


FIG. 23.

"In 1860 another attempt was made, by Robert Gamble, Jr., to apply this principle in a more practical device. It consisted of a

* Report of Chief of Engineers, 1867, pp. 419-427.

† Reports of Chief of Engineers, 1878, p. 654, etc.

‡ These quotations are taken from a paper by the writer and may be found in the Proceedings of the Engineers' Club of Philadelphia (Vol. vi, 1886-1888, p. 73, etc.), but Figs. 23 to 27 are added and there are also some other slight changes to make the matter more complete.

Mr. Haupt. floating barge (Fig. 24), having a false bottom hinged near the upstream edge The bottom was composed of two leaves, the lower being kept horizontal as it was pressed down by four spuds, while the upper was made to flare up stream to deflect the current under the boat, and so wash out the bar upon which it had grounded. The action in this case, it will be seen, was limited and temporary, and did not differ, in kind, from that of an ordinary scow, which, being anchored over a shoal, will cause the removal of the sand under it for a depth nearly equal to its draught.

"A third device was that proposed by J. Grant, a Mississippi River pilot, in 1876, who tried to remove bars by placing a barge, having heavy scantling suspended on its side, athwart the current. Attached to the bottom of the scantling there were flaring shields, 3½ ft. wide, extending the whole length of the boat, 80 ft., by which the currents near the bottom were deflected downward. This machine was placed near the upper end of the shoal to be removed, and the aprons lowered to the required depth, when it was found that the current was forced under it with increased velocity, and the material was quickly excavated, thus allowing the barge to float down stream, guided by a tug, and shearing off the top of the bar as it went. 'When a deepening of about 6 ins. had been effected over the whole area required, the apron was lowered still deeper, thus shaving off the shoal by successive cuts.' By this means a deepening of about 2 ft. was effected, but when operations ceased, the bar reformed.* This serves merely to demonstrate the correctness of the principle of vertical deflection, for in this instance the feeblest currents or those near the bottom were the ones applied, and that only for a very limited depth. There was the fatal defect of not providing for a permanent change of regimen at that section, for no mere change of mould without a corresponding change in velocity will produce a permanent channel."

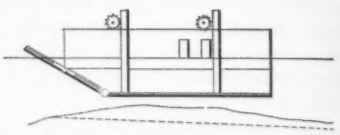


FIG. 24.

In 1880 Taylor patented an intricate device of a weighted triangular box, a floating barge with movable truck, a submerged pilot wheel, an articulated brace or leg, and other complicated parts.

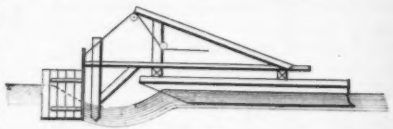


FIG. 25.

Koon's device, of 1883, consisted of a series of deflecting plates set in a box, or frame, having legs which rested upon the bar, but the writer has never seen any record of a trial having been made.

"*Economy of Current Deflectors.*—As to the economy of this method of dredging as compared with the mechanical devices, reference is made to a crude and limited construction (Fig. 25) used on the Garonne in France; where, notwithstanding its imperfections, it was found quite efficient. The account says: 'An economical manner of removing the materials of the bed of a river consists in the application

*The Mississippi Jetties. Corthell, p. 216.

of movable dams attached to a boat. These dams offer a resistance to the flow of the water, and, according to the greater or less depression given to them, they either divert the whole effort of the stream against any particular object, or by simply contracting the water-way they augment its velocity, especially at the bottom. Wherever applicable this system has been found to diminish the expense by about nine-tenths.' Mr. Haupt.

"'The machine which was employed on the Garonne removed about sixty yards of sand and clay per day, at an expense of about 2¼d. (5 cents) per cubic yard.'

"(Extract from the '*Aide Memoire*,' Vol. 3, p. 273).

"It appears that this dam was a kind of vertical screen attached to the up-stream end of a scow to contract the waterway."

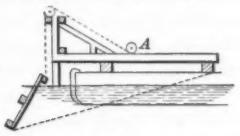


FIG. 26.

The "Kingston" deflectors (Fig. 26) as applied on the Hooghly River, India, cut from 6 ins. to 2 ft. through a bar 300 ft. long in two hours at low water.*

The experience of the writer inclines him to the belief that current deflectors are very effective auxiliaries to channel improvements, but they should be accompanied by permanent regulating works to maintain the benefits which they produce and augment. Fig. 27 shows a current deflector designed by the writer some years ago.

Under the subdivision of water jets, etc., the writer is impressed with the failure to refer to the pioneer and basic patent for the system of removing spoils from the bed of a river or bay by means of rotary cutters with inward delivery, centrifugal pumps and flexible distributing pipes, as issued to Mr. A. B. Bowers, C. E., of San Francisco, and which has been applied so extensively in various modified forms on rivers and harbors, to the great benefit of commerce. The claims of the patentee have been uniformly sustained by the United States courts, and the inventor's time is consumed in efforts to protect his interests, the history of which reads like a romance. Active opposition to an invention is, however, the best evidence of its merit. These dredges were used at St. Louis, on the Mississippi; on the Chicago drainage canal; at Seattle, Tacoma, Alameda Bay and, in modified forms, on the Atlantic and Gulf coasts, with great effect.

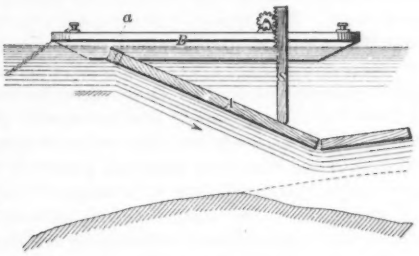


FIG. 27.

* For details and drawings see *Scientific American*, November 24, 1888, p. 326.

Mr. Haupt. Under Section 7 the author says: "The removal of bars by means of blasting has been tried with unsatisfactory results." If this statement is understood as being limited to the experience on the sand bars of the Mississippi River it may doubtless be correct, otherwise it is open to criticism, since other instances of the successful removal of bars may be cited, one of the most conspicuous being that of the Brunswick Bar, Georgia, where the depth was increased from 17 to 24 ft. by the explosion of dynamite aided for the last foot or more by devices for smoothing the bottom, and the results appear to be fairly permanent, while the cost was a mere fraction of that which would have been required had jetties been built.

This excellent paper is, however, too extensive to be discussed in detail, and the writer believes that the temporary improvement of the Mississippi, at low-water stages, by dredging is doubtless the most expedient method of maintaining a navigable channel, especially with the hydraulic dredges which have been so well developed under the Commission. The capacity of these dredges reached, in one case, 2 553 cu. yds. per hour, an achievement which would have been regarded as utopian but a few years ago, when the average was 1 000 cu. yds. per day.

The adoption of the dredging system, for the improvement of the river, marks a radical departure from that used in the earlier stages of its development, when these modern facilities were not available; but, as the author states, the making of each cut involves a special problem, and the results are not permanent, but must be repeated at each low-water stage. That this may be done economically it should be remembered that a lateral displacement of material, especially if placed on the down-stream edge of the cut, when it is not parallel with the axis of the current, will produce the best results, both by concentration and reaction. A change of form in the wetted perimeter without an increase in the area of the section is what is desired; hence, in general, a longitudinal movement of material, unless it be intended to produce uniformity of section and flow, would prove injurious.

In conclusion the writer submits another brief extract from his paper on the improvement of rivers by regulation works.*

"With reference to the improvement of the Mississippi River, the plan of the Commission as stated by Mr. Jas. B. Eads, C. E., was to rectify 'the high-water channel by the ultimate narrowing of the wide places as the only method by which a deep and uniform low-water channel can be permanently secured.' 'A uniform current will result; the caving of the banks will be practically arrested, and the sooner these wide places are corrected, the less will the improvement of the river cost.'†

"In a stream, the improvement of which may cost over $100 000 000, it is of great importance that the most economical and permanently effective devices be used.

* For further data see also article on Dredging, in Johnson's Encyclopædia by L. M. Haupt.

† N. B.—The policy of the Commission having changed, Captain Eads withdrew.

"It is evident that the velocity of a stream is affected by the amount or quantity of water, and the area of its section. If the latter be made larger for a given quantity, the velocity will be reduced; if smaller, increased: or, if the quantity passing a given area be increased or diminished, the velocity must vary in the same ratio. Mr. Haupt.

"It is also apparent from the preceding quotations that in the opinion of the most experienced hydraulic engineers, the only forces that can be applied with success to secure permanent improvements are those of tidal and river currents. Hence that system which most readily controls and regulates the currents will give the best permanent results in curbing the stream."

A. W. ROBINSON, M. Am. Soc. C. E.—This paper is valuable and timely as a historical record of a most remarkable work. The author's familiarity with the Mississippi has enabled him to describe the peculiar conditions which there exist, and to make clear the reasons and considerations which have governed the development of a unique system of dredging. In the low-water season on the Mississippi events follow one another rapidly. A dredge that can make an available channel across a newly developed shoal in a few hours and permit navigation to be resumed can fairly be called a unique production. Mr. Robinson.

The author has described the first efforts made in this direction and the rapid development of a distinctive type of dredge from the *Alpha*, of 1892, to the machines now being built. Four of the dredges described in the paper were built by the Bucyrus Steam Shovel and Dredge Co., namely, the *Ram* and the *Gamma*, both from the writer's designs, and Nos. 3 and 4, as described on page 293, from Major Handbury's designs.

In the construction of the earlier dredges there was some difference of opinion as to the relative value of different features. The committee having the matter in charge determined to construct different dredges to test the most promising designs. For instance: It was thought by some that mechanical agitators were indispensable for efficient work, and the good work done elsewhere with rotary cutters, etc., was cited; on the other hand, there were those who contended (the late Colonel Henry Flad and the writer, among the number) that, while mechanical agitators were useful and even indispensable under certain conditions, they were unnecessary in the free, alluvial sand of the Mississippi River. Experience has proved that the cutter appliances only add complication and liability to delay, and that better results are obtained with water-jets, or in fact with no agitation at all. It is only necessary to bring the mouth of a suction pipe into proximity with the sand, and to feed it regularly, in order to obtain all the sand that the pipe is capable of carrying. If the open end of a plain suction pipe is fed into a bank of free sand, it is always possible to choke it by taking more sand than the water will carry. Observation of the early work of these dredges shows that there was no difficulty in getting sand into the pipe in any quantity, and that the main thing was to put it through in large quanti-

Mr. Robinson.

ties without choking and without sinking the pipe. This question of mechanical cutters *versus* water-jets is, therefore, one which should be determined entirely by the conditions to be met and the kind of material to be dredged. In free sand neither are necessary. In sandy alluvium, soft mud, or stratified deposits easily separated, the water-jets will be sufficient to break up the bank so that it will offer no resistance to pumping. In harder material, requiring cutting and disintegration, mechanical force must be applied as well as hydraulic force. These and other questions have been settled by the experience gained, and while all the dredges, as a series, are remarkably successful, the later ones are naturally more perfect and efficient.

The first floating discharge pipes made had insufficient buoyancy. It was thought that more than 25% of sand never could be carried in so large a pipe, but later it was found necessary to provide a margin of buoyancy even with the pipe solidly full of sand, a condition which sometimes occurred. Owing to the great size and weight of these discharge pipes, the general practice has been to carry them partially submerged. This caused some inconvenience in fitting on the rubber connecting sleeves, but made it possible to use smaller pontoons. In the pontoons of the *Gamma* each section consisted of four cylindrical pipes clamped to one length of discharge pipe 50 ft. long. Four clamp frames on each length served to bind the whole rigidly together into one pontoon, without using any riveted fastenings or making any holes in the floats. This construction gives great stability against overturning, and also admits of turning, removing, getting at or replacing any of the floats, without difficulty. It is also cheap and easy of shipment. The side-floats of the *Gamma* were made a little smaller in diameter than the main central pipe. Experience showed that it would have been better to provide more buoyancy by making the side pipes at least of the same diameter as the main discharge pipe.

The pontoons of the *Beta* were rounded on the bottom, with the object of diminishing the resistance to the current when the pipe-line is deflected or lying across the current. They were, however, deficient in stability and were liable to capsize. In dredges Nos. 3 and 4, Major Handbury has treated the pipe-line question in an entirely different manner. Instead of a floating pipe 1 000 ft. long, deflected across the current and subject to its resistance, he proposes to use a pipe 500 ft. long, and carry it straight out laterally, at right angles to the current if necessary. This is accomplished by mounting the pipe on a series of boat-shaped pontoons with swivel supports on each. The pontoons are sharp at bow and stern, are each provided with a rudder, and can be so steered and set that they will carry the pipe out, at any desired angle from the dredge, in a rapid current, without any deflecting lines or anchorage whatever.

The enormous output made as a test record by the *Beta*, in spite of

many and serious mechanical defects, is a proof of what sand and water will do when brought within the range of the suction of 2 400 H.-P. The cutter appliances of the *Beta*, consisting of six vertical cylindrical steel cutters 6 ft. x 6 ft., operated by 26 bevel and other gears, contributed in nowise to the result, except possibly as a strainer to admit water and thus prevent choking, for only the extreme lower end of the cutters ever came in contact with the sand. Mr. Robinson.

As a result of the experience gained the entire cutter system of the *Beta* has been discarded, and also the auxiliary engines and winding gear, and the dredge fitted with a water-jet suction and anchor winches, practically on the design of those used on the *Gamma*.

In the matter of boilers for these dredges there is some difference of opinion. Three of the dredges are fitted with Heine water-tube boilers, and the remainder with externally fired, cylindrical, return-flue boilers, set in brick-lined casings—otherwise known as "Mississippi River" type. The *Ram* has cylindrical, internally fired, tubular boilers. The old river type of boiler has remained unchanged for many years, and steamboat men have become so accustomed to it that its use is second nature to them, and they naturally regard the modern mechanical refinement of a water-tube boiler with suspicion and distrust. The old-fashioned boiler answers the purpose well enough with unskilled labor and in muddy water, and for these two reasons, as well as for the fact that it is cheaper in first cost, it has the advantage.

The result of the experience gained with the six previous dredges may be expected to be found embodied in the latest dredge which is now to be built for the Mississippi River Commission.

The *Beta*, *Delta* and *Gamma* were ordered by the Mississippi River Commission from Lindon W. Bates, the New York Dredging Company and the Bucyrus Steam Shovel and Dredge Co., respectively, for the express purpose of demonstrating whatever merit there may have been in the three designs. The commercial results shown by the tests of these three dredges may be indicated briefly by the following figures taken from the paper:

Dredge.	First cost.	Operating expenses per day.	Test Output.	
			Average cubic yards per hour.	Cubic yards per horse-power per hour.
Beta	$218 162	$221.63	4 920	2.00
Delta	124 940	111.76	1 829	1.62
Gamma	85 530	100.51	1 523	3.28

The Mississippi River Commission is now in possession of many data and results of practical work, and the dredge recently called for in

Mr. Robinson. the specifications issued June 21st, 1898, may be assumed to be based on careful study of the performance of those already in service.

The following points are noted in these specifications:

(1) Boilers of the river steamboat type are retained.

(2) The main pumps and engines are of the *Gamma* type, improved in detail.

(3) The feeding and hauling winches are practically of the *Gamma* type.

(4) The dredge is to be self-propelling.

(5) The discharge pipe is to be 500 ft. long, and carried on top of pontoons instead of being partially submerged.

The results of the comparative tests that were made, as given in the paper, cannot fail to be of interest. Such tests could only be made by the Government, as they involved expense that no contractor or private corporation would care to incur. While, in the main, the tests appear to be reliable and accurate, some of the statements are open to question: For instance, on page 285, in the tests of the *Epsilon*, and in the third and seventh tests the efficiency is given as 83.6 and 91.8%, respectively. As this efficiency is the percentage of the foot-pounds of work done by the pump to the foot-pounds of work represented by the indicator diagrams of the engine, it represents the combined efficiency of both pump and engine. The power consumed in internal friction of the engines is not given, but, assuming it to be 10%, this would make the net efficiency of the pump 92.9 and 102%, for the tests in question. Needless to say, such a result is impossible. Something appears to be wrong in the velocity of discharge. In Test No. 6, with 738.3 I. H.-P., the velocity is 16.6 ft. per second, and in Test No. 7, with 717.1 I. H.-P., the velocity is 18.3 ft. There is not sufficient information as to the details of the observations to enable an intelligent criticism of the causes of these discrepancies to be made. Slight errors in the observations or instruments and changes in conditions might cause great variation. The velocity of discharge appears to have been computed on the assumption that the entire cross-section of the pipe was moving, whereas this may or may not have been true.

Mr. Ockerson. J. A. OCKERSON, M. Am. Soc. C. E.—The author is highly gratified with the scope of the discussion brought out by the paper. The records of the experiences of different engineers working in different fields on similar problems are exceedingly valuable to those who come after them. The paper has at least served a good purpose in bringing out these individual expressions.

In reviewing the discussion it may be well to state that the author did not intend to exhaust the subject in the brief space of a single paper, and purposely omitted descriptions of many channel improvement devices that have come to his notice. It may also be well to

state that he aimed to limit himself to devices proposed for, or used on, the Mississippi River. Mr. Ockerson.

With these explanations Professor Haupt will understand why the author failed to "refer to the pioneer and basic patent," etc., and also omitted the mention of many devices, several of which have been described by Professor Haupt.

As a further illustration of the silting up due to the retarding influence caused by contact with the bottoms of barges and boats, it may be mentioned that where large fleets of plant are tied to the banks for considerable periods of time the shoaling frequently becomes so serious as to necessitate their removal to some new site.

A dredge and its fuel barge left in the dredged cut has been known to fill it up to such an extent as to obliterate the cut in a single day.

Mr. Edward Flad in his discussion disputes a statement made by the writer with regard to the results obtained with jets and mechanical agitators.

The following extracts from the official reports may throw some further light on the question. The engineer officer in charge says:

"The *Zeta* differs from the *Epsilon* in the use of a mechanical agitator in place of a water-jet agitator. On account of the numerous break-downs on this dredge, which did not amount to enough to cause a rejection, but did indicate her inferiority as a working machine, it was finally determined to add a water-jet agitator, and the necessary machinery for the same has been ordered."

The mechanical engineer under whose supervision the dredges were built, says:

"The dredge *Zeta* which was fitted with a mechanical agitator, did not pass the ordeal of testing so satisfactorily. * * * The record of these tests is a record of stoppages to put in new shearing pins. * * * The performance of this agitator was considered so unsatisfactory that it was deemed inexpedient to take the field relying solely upon its help to loosen material for the pump. * * * The results of the tests of the *Zeta* (which is a duplicate of the *Epsilon* with the exception of the agitators) show a decided diminution in the quantity of sand delivered, which may be accounted for by the difference in the efficiency of the agitators; the average of five tests with the *Zeta* being 1 364 cu. yds., and of the *Epsilon* 2 553 cu. yds., of sand per hour."

The superintendent of dredges, under whose personal supervision all the tests were made, says:

"It was found, while making the tests with the *Epsilon*, that the best capacity test was obtained when pulling ahead at the rate of about 9 ft. per minute. When the test of the *Zeta* was commenced it was found impossible to pull the dredge ahead at that rate, owing to constant breaking of agitator shearing pins. It was therefore necessary to reduce the speed of advance down to less than two-thirds of that of the *Epsilon*, in order to have the shearing pins last long enough to make the barge test. * * * It was not thought advisable to increase the size of these pins beyond $1\frac{3}{8}$ ins., as it might

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break either the bell-crank or some other part of the machinery which was becoming badly racked. * * * It was therefore decided to purchase a jet pump and place it on board in connection with this agitator for use in the field, as the capacity of the dredge was cut down nearly one-half, owing to the mechanical cutter."

The above reports were written before the dredges had been used in actual channel dredging. Since then, they have seen some three months' service in actual work, which has verified the above conclusions as to the mechanical agitator.

Mr. Flad also states that the writer is mistaken in saying of the agitator, "It will therefore be taken out, and jets will be put in." Jets have been put in, and the mechanical agitator has been taken out and is now lying on the "plunder barge." This, however, was not done until it was tried in average river sand under ordinary working conditions and found to be deficient as an agitator.

With this slight exception, the dredges *Epsilon* and *Zeta* have proven in actual work to be excellent dredging machines.

Mr. Robinson's discussion is of special interest owing to his wide experience as a designer and builder of dredges. He seems to question the reliability of some results of the tests that have been described. It should be borne in mind that in these tests, the dredges are put to their best paces for a short interval of time, and therefore may be expected to develop an unusual degree of efficiency.

There is one feature of the tests as recorded in the tabulations which should be explained. The test barge is 1 000 ft. away from the pump when the tests are made. The indicator cards, revolutions of pump and other items pertaining to the mechanical performance of the dredge, used in deducing the results are determined at the time when the valve in the barge is open. The distance between the two being so great, and the time interval so short, the conditions noted at the dredge may not reach the barge until after the valve is closed. As the material is continually changing in both character and quantity this may account for some of the apparent discrepancies. The reason the observations at the dredge and at the test barge are not made so as to cover the same conditions is because the operators at the dredge are not permitted to know when the valve in the barge is to be opened. In this way the natural disposition to have the pipes filled to their limit with sand, just as the test is made, is in a measure obviated.

It must not be supposed, however, that equal indicated horsepower will give equal velocity of discharge, as it is no uncommon thing for the suction head to change 50% in a brief interval of time. This is due to the variations in the character of material, which at times does not readily enter the suction. Considerable power is therefore used up at the suction side of the pump.

Mr. Robinson says: Mr. Ockerson.

"Something appears to be wrong in the velocity of discharge. In Test No. 6, with 738.3 I. H.-P., the velocity is 16.6 ft. per second, and in Test No. 7, with 717.1 I. H.-P., the velocity is 18.3 ft."

He failed to note that in the first case the suction head was 17.0 ft. and in the second case 14.7 ft., while the delivery head remained the same in the two cases.

The velocity of discharge is "computed on the assumption that the entire cross-section of the" discharge pipe flows full during the test.

The total volume found in the test barge divided by the number of seconds occupied in filling the barge, gives the volume per second. This volume, divided by the area of the discharge pipe, gives the velocity of flow per second. With the pump running uniformly at the normal speed, and with the high velocity of discharge attained, it does not seem probable that the section of the pipe is materially reduced by a deposit of sand at rest on the bottom.

Under abnormal conditions, such as running the pump at a very high speed so as to cause a slip, there would be a very low discharge velocity. This would very seldom happen with the large sized pumps in use.

The observations of all kinds, recorded during the tests, were made with great care and are believed to be reliable as far as they go. If there are discrepancies in the results that cannot be explained, it should be remembered that, in dealing with steam and water, the laws governing their expansion and flow have not as yet been fully and satisfactorily defined.

Mr. Mitchell says:

"Occasionally a dredge-cut, without other work to maintain it, may deepen and improve, and become the permanent channel for that low-water season, but more often it will require a repetition of the work of the dredge," etc.

This is contrary to the experience on the lower river. The cases where dredging has to be repeated during the same low-water season have thus far been exceptional. When there are considerable oscillations of stage, the cuts sometimes fill.

During the present low-water season there have been several oscillations ranging from 2 to 10 ft. or more. In one case a cut that had been completed was found to be filled up by the rise in the river, and preparations were made to open it again when the river fell. A survey at that time developed the fact that the material which had filled loosely into the cut was all washed out again.

The work of the present season coincides with the experience of previous work, to the effect that a cut once well opened will generally remain in good condition during the low-water season, and, perhaps, even longer. The exceptions are probably due to faulty

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locations, or unusual changes in the local regimen or in the stage of the river.

The use of pontoons for sustaining the discharge pipes has some advantages over the floating discharge pipes, the chief of which is to be found in the facility with which the successive lengths can be coupled, as the pipe lies entirely above water. It can, perhaps, also be deflected more readily than the floating pipe line. In practice there has been very little trouble with the latter. As far as simplicity and facility of handling in towing are concerned, the floating pipes seem to be better than the pontoons.

Mr. Woolley's description of the work done at the mouth of the Red River is a very interesting account of a successful piece of hydraulic dredging.

In regard to the length of discharge pipe necessary on the bars of the Mississippi River, Mr. Woolley questions the necessity for using a discharge 1 000 ft. long. There are many cases where a length of 500 ft., or even less, is ample, and in such cases the shorter lengths are very generally used. There are also cases where lengths of 1 000 ft. are essential. The results of tests with different lengths of pipe will be found in the tabulations of tests.

It has apparently been a matter of surprise and disappointment to some that no figures have been given as to the amount of material moved in dredging, and as to the cost of doing the work, based on cost per yard.

Where there is so much material moving from natural causes, it is impossible to arrive at anything like an accurate measurement of the amount of material that actually passes through the pumps when dredging in the channel.

Objection has also been raised to the method used in determining the capacity of the dredges, as the time involved in the barge test was so brief. At the suggestion of the writer, tests have been made recently which meet the last objection. They were made by the regular crews which have been engaged in channel dredging, and as nearly under the normal working conditions as practicable.

In making these tests the dredges were operated in a "pocket" behind a sand bar where there was no current to bring in or carry away material, and where the sand was very nearly the same as channel sand. It will be seen that these tests cover ample time to give good working results.

Before beginning the tests the site to be dredged was cross-sectioned with great care, and this was also done after the test was completed. This gave the data from which the volume handled by the pump was readily computed. The results obtained are as follows:

Dredge *Gamma*. Test made from October 31st to November 3d, 1898: Mr. Ockerson.

Time of actual dredging	45½ hours.
Total length of cut made	4 566 ft.
Average depth of cuts	7.1 "
Average advance per hour	100.3 "
Cost per lineal foot of cut	$0.0898
Total volume moved	45 856 cu. yds.
Average volume moved per hour	1 008 " "
Cost per cubic yard	$0.0089
Average steam pressure	145.6 lbs.
Average number of revolutions of main pump per minute	150.0

Dredge *Delta*. Test made from October 30th to November 3d, 1898:

Time of actual dredging	27 hrs. 23 mins.
Total length of cut made	2 711 ft.
Average depth of cut	6.5 "
Average depth of suction	13.6 "
Average advance per hour	99.0 "
Cost per lineal foot of cut	$0.0926
Total volume moved	34 462 cu. yds.
Average volume moved per hour	1 255 " "
Cost per cubic yard	$0.0073
Average steam pressure	151.1 lbs.
Average number of revolutions of main pump per minute	140.9

In both of the above tests the material was delivered through 1 000 ft. of discharge pipe.

The cost given only includes the cost of actual dredging time. The *Delta* began the tests with a defective cutter shaft which caused considerable delay; an unusual amount of driftwood was encountered, and this also caused delay. Including all these delays, together with time used in placing plant, changing cuts, etc., the cost becomes $0.147 per lineal foot and $0.0116 per cubic yard. On cuts 3 and 4 the *Delta* was pulled ahead at the rate of 138.3 and 177.5 ft. per hour, respectively, or as fast as the material could be carried away by the discharge pipes. The capacity per hour, under these conditions, was found to be 2 550 cu. yds., which may be considered as very near the maximum under favorable working conditions.

Dredge *Zeta*. Tests made November 3d to 6th, 1898.

The chief object of this test was to ascertain the facility with which a dredge with water-jet agitators could be operated through a sand bar, a portion of which extended above water. Otherwise the conditions were essentially the same as those noted in connection with the other dredges, except that the suction extended into mud which clogged the opening and developed a high suction head with an abnormally low discharge.

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The dredge readily cut her way into a dry bar for a distance of 550 ft. and an average width of about 200 ft. The suction was lowered to a depth of 17 ft. below the water surface, and the bar extended about 4 ft. above the water, giving a working face of about 21 ft. Cuts 1 and 2 were made with 500 ft. of discharge pipe, and the other four cuts with 350 ft. of pipe.

The results may be summarized as follows:

Total time of actual dredging	62 hrs. 55 mins.
Total length of cut made	1 785 ft.
Average depth of cut after dredging	11 + ft.
Average depth of suction below top of bar	20.6 ft.
Average advance per hour	31.1 ft.
Average cost per lineal foot	$0 307
Total volume moved	35 287 cu. yds.
Average volume moved per hour	562 cu. yds.
Average cost per cubic yard	$0.015
Average steam pressure	147 lbs.
Average number of revolutions of main pump per minute	180

This test must not be confounded with tests made under normal conditions, and the volume moved per hour is no measure of the capacity of the dredge under such conditions, but it serves a good purpose in showing what the dredge will do under the extraordinary conditions described. The small volume moved per hour may be attributed to the presence of mud in considerable quantities. This doubtless served to clog the suction and check the proper flow of material to the pump.

These tests, covering, as they do, a comparatively long period of time, give results which may be accepted as a fair measure of the normal working capacity of the dredges *Gamma* and *Delta*. The capacities given would probably be exceeded somewhat when working in channel sand, as the material is easier to handle than the finer sand found in the upper bars.

In closing this discussion it might be well to state that the results attained during the low-water season of 1898 have been very encouraging for dredging as a means of temporarily improving the low-water navigation of the river. It is true that the stage of the river throughout has been above the normal low water. The oscillations in the stage have been frequent, and this condition is, in general, detrimental to dredged channels.

Five dredges have been at work at such times as the stage was low enough to enable the suctions to reach the bottom. As a result of this dredging it can be said that in every case where dredging was done the depth was increased from 1 to 5 ft. for a navigable width of 250 feet or more.